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The Impact of drinking water source on disease transmission among pastoralists: The Case study of the Ngorongoro Conservation Area, Tanzania.

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abstract

The study examined the impact of drinking water source on disease transmission among pastoralists, using a case study of the Ngorongoro Conservation Area (NCA) in Tanzania. A total of four villages located in the NCA were sampled and studied, namely: Endulen, Nainokanoka, Kayapus and Meshili. This was a cross-sectional study which deployed questionnaires, direct observation, document reviews and focus group discussions. A total of 396 households participated in the survey. The collected data were analyzed using qualitative data analysis techniques and descriptive statistics such as frequencies. The study findings revealed that unfiltered waterholes shared among humans, livestock and wildlife accounted for 82.1%; indicating that it was the primary source of disease transmission. Other sources of disease transmissions were: the use of untreated tap water, rivers, spring water and rainwater. The factors influencing the use of unfiltered waterholes were limited access to tap water, scarcity of drinking water sources, drought, population increase and tourists. The co-usage of water coupled with lack of latrines suggest fecal contamination of drinking water sources. Women were more susceptible to waterborne diseases as they were more directly engaging in all domestic activities including fetching for water as compared to men. The waterborne diseases affecting pastoralist communities were diarrhea, cholera, skin infection, dysentery, worms and typhoid fever. The study concluded that there is a nexus between shared drinking water sources and the prevalence of high anthrax *(Bacillus anthracis)* infection rates. It is recommended that the adverse impacts of disease transmission on drinking water sources can be mitigated through increasing supply of tap water, using treated water and encouraging community use of pit latrines.

Introduction

The Ngorongoro Conservation Area (NCA) in Tanzania was established in 1959 as a multiple land-use conservation area in Tanzania in which the Maasai and Datoga pastoralists and Hadzabe hunter-gatherers could cohabit with wild animals for mutual benefits (Nyerembe and Bushesha, 2021; Ngorongoro Conservation Area Authority-NCAA 2011; McCabe et al. 2010). These benefits ranged from revenue collection from tourists used for wildlife conservation supporting communities residing in the area (Melita and Mendlinger, 2013).

It was anticipated that the area could potentially generate the income to finance a number of social welfare activities including: students scholarships, construction of health centres and schools, grazing, provision of food grains to lessen food scarcity and insecurity in the communities, create market for handicrafts from cultural bomas (houses/shelters), provision of ambulance for health emergencies, fees for traditional dancing and obtaining herbal medicinal plants for treatment of diseases (Kegamba et al. 2023; URT, 2022b; Kaaya and Chapman, 2017).The sharing of the benefits generated from the protected areas was intended to instill positive attitudes held by the communities toward conservation of wildlife (Parker et al. 2022).

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The NCA is among the hot spot areas of human-wildlife interactions in the world. It is inhabited by the Maasai pastoralists who are nomadic and semi-nomadic herders who rely on their livestock for food, income, and cultural status (Gustafson et al. 2015; Lawson et al. 2014; Lybbert et al. 2004). The Maasai pastoralists have been living in the NCA for almost 200 years ago. *Datoga* who are part of the residents of the NCA were forced to move by the Maasai. Presently, they remain the minority and they are found in the South-eastern part of the NCA. The Hadzabe ethnic group resides on the edge of the NCA by Lake Eyasi (Kaswamila, 2020; Briggs, 2006). It is reported that the Maasai have steadfastly continued to maintain their traditional ways consistently beneficial to wildlife conservation (Linuma et al. 2022; Fosbrooke, 1972).

The area has high biodiversity and is inhabited by diverse species of mammals, birds, and reptiles such as elephants, buffalos, leopards, lions, wild dogs, cheetahs, and spotted hyenas (WWF SARPO, 2005). The Maasai pastoralists have been co-existing with wild animals in the area for hundreds of years (Linuma et al., 2022; Homewood and Rodgers, 1991). This long history of cohabitation with wildlife resulted in accommodation and co-existence (Nelson et al., 2012; NCAA, 2011). The co-existence among Maasai, livestock, and wildlife threatens natural resources, especially due to water pollution. As argued by NCAA (2019), the only source of drinking water is groundwater which is contaminated by wildlife fecal matter, hence posing threat to health of the Maasai.

However, the Maasai pastoralists rely on natural resources such as pasturelands for their livestock, traditional herbal medicines, while the water supply is limited (TAWIRI, 2020; Mkiramweni et al. 2016; UNEP-WCMC, 2012; State Party of Tanzania, 2012). Access to natural resources such as water and forage is restricted due to sharing of resources with wildlife, climate change and tourism (Paasche et al. 2022; Dreibelbis et al. 2013).

Water is collected often by women and girls, mainly from waterholes, rivers, and spring water and such collection is associated with many risks such as the physical burden of carrying heavy loads of water which might cause injury (Henderson et al. 2016). Other risks include possible attacks by wild animals including buffaloes, elephants, and snakes on the way to and from water sources (Hovden et al. 2020). Donkeys are dubbed as "the woman's car" used to transport heavy buckets of water; but only a few people in the NCA manage to possess donkeys because the communities are poor (Hovden et al. 2020).

programmes towards the realisation of health-related SDGs.

Sharing of water has been linked with transmission of infectious diseases such as cholera, diarrhea, dysentery and anthrax (Linuma et al. 2022; Homewood and Rodgers, 1991). The sampled water taken from water sources such as waterholes, rivers and spring water in the NCA have demonstrated contamination by fecal coliform and total coliform bacteria (The United Republic of Tanzania (URT), 2021). This suggests that, apart from fecal bacteria, there might be other bacteria in the water sources. Studies carried out by Mellou et al. (2014) and that of Shamsu-Deen (2013) have reported that the water quality in NCA is a transmission path for infections, diarrhoea and other diseases.

Humans can be affected by waterborne diseases through ingestion of contaminated water, during farming activities in stagnant polluted water, or recreational activities. The sharing of water with wildlife and livestock in the absence of water treatment tabs once resulted in the outbreak of cholera (NCAA, 2019).

Likewise, TAWIRI (2016) reported that the outbreak of anthrax in 2016 in Ngorongoro was linked to water sources. URT (2021) adds that animals tend to contact *Bacillus anthracis* spores when grazing closer to the soil when grasses are sparse due to increased interactions with wildlife when water is scarce. A study done by TAWIRI (2016) also reported an outbreak of anthrax in NCA in 2016, infecting humans with fatalities caused by sharing of resources such as water.

The outbreak was also reported in the Serengeti ecosystem located closer to the NCA killing goats, cattle, sheep, affecting humans and wildlife (Hampson, et al. 2011; Lembo et al. 2011). To better understand the contact rates between pastoralists and wildlife driven by shared water usage, we performed a questionnaire-based study of the water sources in NCA. Specific water sources of high risk of wildlife co-usage were identified and potential mediation strategies are suggested in this paper.

Materials and Methods

Study area

The study was conducted in the NCA in the Ngorongoro district in Arusha region, Tanzania. It covered four villages of the Kayapus (n = 82), Meshili (n = 124), Endulen (n = 118), and Nainokanoka (n = 72) (Figure1). The NCA was selected purposively mainly due to three reasons: First, it is the first multiple land-use conservation area long established in 1959 to allow Maasai and Datoga pastoralists and Hadzabe hunter-gatherers reside within protected wildlife area (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 (NCAA, 2011).

Criteria for selection of case study villages

The deterministic sampling approach was used to select the case study. The criteria listed in Table 1 were used to identify the villages of interest. The criteria used were measured using scores ranging from 1-5, (1 = least applicable and 5 = most applicable) to determine selection of wards and villages as depicted on Table 1.

Inferring from Table 1, the villages selected were those directly relying on unsafe drinking water sources, high population density, absence of toilets, increase of wildlife, sharing of drinking water sources, prevalence of waterborne diseases such as diarrhea, poor waste management and limited supply of tap water.

This study was carried out in the NCA, which is made up of nine villages namely; Nainokanoka, Irkeepus, Bulati (Nainokanoka ward), Oloirobi, Kayapus, Mokilal (Ngorongoro ward) Endulen, Nasporing (Endulen ward) and Meshili (Olbalbal ward). The NCA is located 180 km West of Arusha in the Crater Highlands area of Tanzania. It is part of the Serengeti ecosystem (Niboye, 2010). It lies between Longitude 36° 1' 38.7466" and 36° 1.645776' E and Latitude 3° 9' 44.8399" and 3° 9.747332' S.

Notably, the villages surveyed are shown to the right of 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 (Linuma et al. 2024; Niboye, 2010).

The NCA covers 8,292 km² and is divided into the Crater Highlands, Salei plains, Eyasi escarpment and the Gol Mountains (Masao et al. 2015; Niboye, 2010). The Salei plains receive little rain. They are dry and dusty, following the winds which transport and deposit 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**									
	Dependence of unsafe water sources	High population density	Absence of toilets	Increase of wildlife	Co-usage of drinking water sources	Poor waste management	Prevalence of waterborne diseases	Limited tap water supply	**Total score**	**Rank**
Nainokanoka	4	5	5	5	5	4	5	4	**37**	**3**
Oloirobi	4	1	4	3	4	4	4	5	**26**	**7**
Kayapus	5	5	5	5	5	5	5	5	**40**	**1**
Nasporing	3	1	4	3	4	4	4	4	**27**	**6**
Meshili	5	5	5	5	5	4	4	5	**38**	**2**
Endulen	5	5	4	4	4	4	5	5	**36**	**4**
Bulati,	4	2	4	2	4	3	4	3	**24**	**9**
Mokilal	4	1	4	3	3	3	4	3	**25**	**8**
Irkeepus	4	1	4	4	4	3	4	4	**28**	**5**

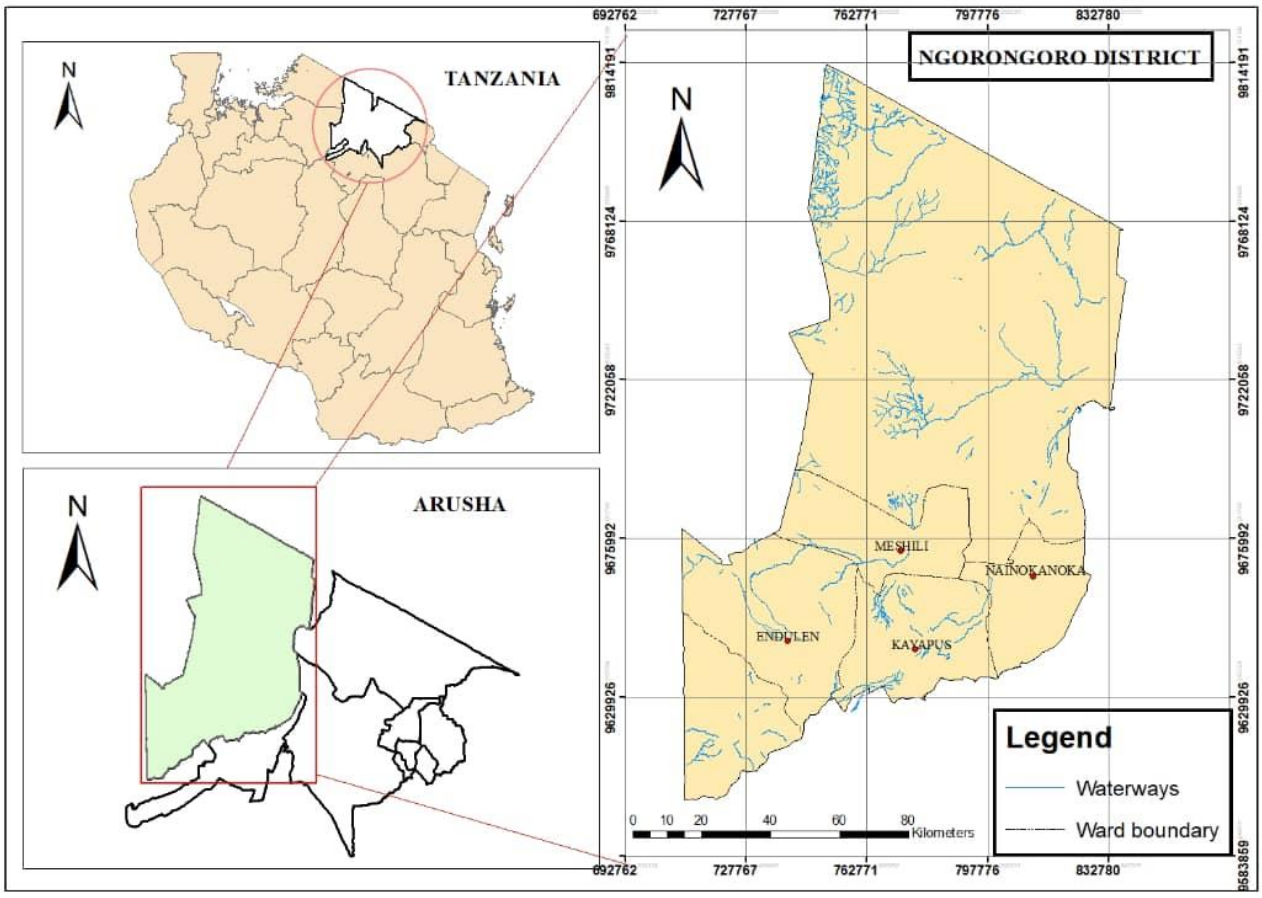

Figure 1: NCA location showing the relative position on the Map of Tanzania

Data collection

The methods employed in the study included household surveys, focus group discussions, documentary reviews, field observation and Key Informant (KI) interviews (Linuma et al. 2024).

A random sampling technique was used to select 396 heads of the households required to participate in the interviews. The sample size was calculated based on the total households in the selected study area. This was determined using the Yamane's formula adopted from Owuor and Mwiturubani (2021), as indicated in Equation (1).

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

Whereby

n = sample size

N = population size

e = precision (0.05)

The households in the villages (Kayapus, Endulen, Meshili, and Nainokanoka) were 40065.

Thus, using the formula, the sample size was as follows:

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

n = 396.

Sampling of households for interviews was randomly chosen using a list of heads of households in each village from village records. From the list selected, names were chosen randomly to obtain the representative population sample to be included in the interviews from four villages. Purposive sampling technique was used to choose the study participants required in focused group discussions (FGDs) and key informants (KIs).

The household interviews were conducted using structured questionnaires. The respondents were asked questions and provided answers orally. This method was used to get overall information on the household demographic characteristics of the household members, people perceptions regarding drinking water source and its impact on disease transmission among pastoralists in the NCA.

Beside the household interviews, KIs interview was conducted to get in-depth and detailed information regarding issues in the NCA particularly those requiring professional or specialized knowledge. A semi-structured checklist of questions with both closed and open-ended questions was used. This method was used to collect information from the respondents presumed to have technical or experts' knowledge of the subject matter, namely drinking water sources and their impact on disease transmission in the NCA.

A total of 19 KIs were interviewed during this process. KIs included medical officers (doctors) (n = 5), water management officers (n = 6), and village executive officers (n = 4) in all villages in the study area. Other issues discussed during KIs interviews were diseases caused by drinking water sources, their historical trends and implications on human health and conservation of wildlife.

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 (i.e. each group) who in Maasai culture were more likely to be familiar with diseases affecting their children.

The selection criteria used to obtain the members to be included in FGDs included length of residence in the project area and age. The respondents aged over fifty years were chosen on the basis of their long experiences, which implied their responses could be more trusted. Sex was also considered due to the structure of pastoralist societies and its potential impact on infectious disease. The data collected through FGDs were tranquilized with data collected from other data collection methods. Attesting to that, field observation was used. During field observation, pictures of various areas and scenarios that provided concrete evidence of the research site were taken. Field observation was made during the reconnaissance phase, data collection period, and post-data collection to observe direct drinking water source and impact on disease transmission. Both published and unpublished documents were also used. These included textbooks, journal articles, internet materials and reports from health centers/hospitals, water management officers, villages, wards, and the NCAA.

Data Analyses

The data collected using households' interviews, focus group discussions, field observation, and documentary reviews were mainly qualitative in nature, thus necessitating the use of qualitative data analysis techniques. Content Analysis (CA) was used to analyze the data collected through FGDs and KIs

interviews. Stemler (2015) and Krippendorff (2012) define content analysis as a method used 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. Evidence from the household interviews was also used to authenticate interpretation. Paraphrasing and direct quotes were used to qualify the KIs and FGD findings. Descriptive statistics using the Statistical Package for the Social Sciences (SPSS) version 25 were used. Moreover, the data collected from the household were analyzed and presented as graphs and tables using the Microsoft Excel 2013.

Additionally, mapping the areas with water sources was done to analyze distribution patterns. The researcher collected data and coordinates from Endulen, Kayapus, Meshili, and Nainokanoka villages and presented them through a map. A handheld GPS (at least 3meters is accurate) was used to take the coordinates. ArcGIS Software application was used to prepare a map.

Results and Discussion

Drinking water sources according to respondents

The respondents were asked to mentioned the existing terminologies used to refer to drinking water sources in the NCA using the Maa language. On this regard, quite a number of words/phrases or terminologies were mentioned. An attempt was made to provide their English equivalents, as follows: *Ilualen/Esilange* = waterholes, *Irkejek* = rivers; *Engare orpomba*= tap water; *Ingonyek orngariak* = spring water, and *Engare enjan* = rain water. Water holes in the local language (*Ilualen/Esilange)* was reported by 82.1% of the respondents interviewed as the main drinking water source among humans, livestock, and wildlife in the NCA, 7.6% *rivers (Irkejek),* 6% tap water (*Engare orpomba),* 3.5% spring water (*Ingonyek orngariak),* and very few (0.8%) reported rainwater (*Engare enjan)* (Table 2).

Table 2: Sources of drinking water in NCA

Variable	Frequency	Percent (%)
Waterholes	325	82.1
Rivers	30	7.6
Tap water	24	6
Spring water	14	3.5
Rainwater	3	0.8
Total	**396**	**100.0**

Source: Field Survey, 2022

A study by Linuma et al. (2022) and NCAA (2011) described NCA as a wildlife reserve where humans, livestock and wildlife co-exist in a wildlife conservation area. This co-existence coupled with the limited supply of tap water leads to sharing of drinking water sources among humans, livestock, and wildlife. The sharing of drinking water sources such as waterholes, rivers, spring water and rain water results in the transmission of infectious diseases such as cholera, tuberculosis and anthrax.

Boussettine (2020) noted that humans can be affected by waterborne diseases through ingestion of contaminated water or through other kinds of contact such as recreational activities in polluted marine waters. Other disease transmissions which have been reported include cholera (which mainly affects humans) anthrax and tuberculosis, all of which attributed to sharing of drinking water sources in NCA. This transmission is catalyzed by the Maasai tendency of keeping large livestock leading to frequent contacts with humans (Otte et al. 2007).

Discussions with FGD revealed that domestic animals and wildlife were reported to defecate and urinate in the shared drinking water sources, consequently contaminating water with pathogens such as *Escherichia coli* from animal and domestic wastes.

Community reported uses of drinking water

The respondents were asked to explain how water is used, using the Maa language. The words emerged from such inquiry included: "ewokoto" referring to drinking water; "Eyarata" referring to cooking; "Engisuja" referring to bathing (taking shower); "Eworoto" meaning cleaning, and "iltibui/Oltibu" meaning dip tank. These terminologies were rated as follows: Drinking as described in the local language "ewokoto" was reported by 52.8% to be used by humans, livestock and wildlife, 31.3% cooking "Eyarata", 10.6% bathing "Engisuja", 2.8% cleaning "Eworoto", and 2.5% reported dip tanks "iltibui/Oltibu" (Table 3).

Table 3: Water Uses in NCA

Variable	Frequency	Percent (%)
Drinking	209	52.8
Bathing	124	31.3
Cleaning	42	10.6
Cooking	11	2.8
Dip tank	10	2.5
Total	**396**	**100.0**

Source: Field Survey, 2022

Water is mainly used for drinking by humans together with their livestock and wildlife in NCA. Bathing, cooking, cleaning primarily for humans only and dipping for livestock. Nonetheless, these drinking water sources are unreliable. They rely on the amount of rainfall, which has been fluctuating due to climate change effects. The effect of climate change has been interrupting the ecosystems such as water quality and quantity, browsing shrubs and the number of livestock (Mkiramweni et al. 2016).

Climate change effects are clearly observed particularly during the dry season with a devastating impact on the communities residing in NCA. It has resulted in scarcity and poor supply of drinking water sources, hence increasing competitions of drinking water sources between humans and wild animals, leading to the potential transmission of diseases. The Maasai and their livestock constantly struggle for water resources and grazing space with vast species of wildlife in the NCA (Kipuri and Sørensen, 2008; Homewood and Rodgers,1991).

Figure 2: Water resource sharing by humans and wildlife
Source: Cosmas, 2022

Feld observation and discussions with key informants disclosed the effects of climate change on the available resources during the summer period (Figure 3). The effects of climate change have limited the movement of wildlife to the plains for pasture, hence most of them remain in the Crater and on the mountain slopes adjacent to the crater where resources were available even during the dry season. The intense drought that occurred in the NCA in 2007/2008 resulted in the outbreak of livestock diseases that killed more than 90% of calves (Tarver et al. 2019; Martin et al. 2008). Moreover, the high mortality of 1,500 buffalo 250, wildebeest and 100 zebras in the NCA was caused by severe drought years coupled with diseases that led to nutritional stress (Mills, 2023; Leweri, 2022; Fyumagwa et al. 2007). The effects of high temperature will continue and may affect other development sectors such as the tourist sector. The lodges where tourists arrive demand sufficient water for consumption which is already affected by climate change leading to scarcity of water. This will intensify the sharing of drinking water sources with great effects on pastoralist communities and wildlife and also disease transmission. Tarver et al. (2019) argue that the anticipated temperature rise poses serious threats to the main resources such as drinking water sources in the NCA and will affect the tourism business.

Increased demand for drinking water

All 396 (100%) of the respondents interviewed reported high demand for drinking water for humans, livestock and wildlife. Increased humans, livestock, and wildlife population and restrictions on water use at the Crater by NCAA had resulted in high demand of water, which was limited led to co-usage of drinking water sources. The Maasai are allowed to reside in the NCA except on the floor of the Crater. As the pastoralist communities are circumscribed from using water in the Crater which in turn triggered the use of unsafe drinking water sources. As stated by Leweri (2022), the Maasai pastoralists are permitted to reside and graze in areas outside the crater with restricted admittance to water sources within the crater. Such restrictions compel the local communities to utilize unsafe water sources causing the transmission of waterborne diseases such as cholera. The widespread of tuberculosis in the NCA is also related to the sharing of drinking water sources. As noted by Billewar et al. (2023) and Lohani et al. (2023), the increase in human population led to high demand for water, fuelwood, poles, and other renewable resources. Furthermore, they claimed that the proliferation in human water consumption is driven by tourism and tourist lodges which exacerbated water shortage. A study by Mkiramweni et al. (2016) pointed out that the water scarcity among pastoralists in the NCA is caused by drought, keeping of large number of livestock and excessive use in tourists' lodges.

Discussion with FGD has shown the rise in human population, livestock, and wildlife thus resulting in increased pressure on restricted drinking water sources. They also reported fecal contamination of those shared water sources. Field observation confirmed the scarcity of drinking water sources likely caused by drought in the NCA for almost 19 years (Figure 4). People travel for long distances of almost 10 Kms in search of drinking water using donkeys to carry water. However, the distance varies from one village to another. This suggests that obtaining water in the NCA is prone to risk of be attacked by dangerous wild animals cohabitating in the area.

Figure 3: The effects of climate change
Source: Field Survey, 2022

Figure 4: Donkeys carrying water buckets
Source: Field Survey, 2022

Sharing of drinking water sources with wild animals

All 396 (100%) of the respondents interviewed reported there was sharing of drinking water sources with livestock, and wild animals, contributing to the risk of disease transmissions. The shared drinking water sources comprised waterholes, rivers, spring water, rain water and tap water. The springs found in various areas in NCA are used by humans, livestock, and wildlife (Savio et al. 2018). Livestock and people around the world are in danger of anthrax spores due to contact with contaminated water, soil, and pasture (Carlson et al. 2019). The prevalence and the widespread of anthrax disease with great effects to humans, livestock and wildlife health in the NCA are connected to sharing of drinking water sources.

Discussions with FGDs' and field observation revealed that there was a sharing of drinking water sources among humans, livestock, and wildlife as indicated in Figure 5.

Moreover, FGDs suggested that the Maasai livestock in NCA are at risk of be infected by Malignant Catarrhal Fever (MCF) originating from the wildebeest grazing in the same area, and sharing the same drinking water sources. As a result, the Maasai pastoralists diverted their livestock away from areas where wildebeest congregated.

Field observation and discussions with key informants revealed the effects of Malignant Catarrhal Fever (MCF) on the livestock (Figure 6). The Maasai pastoralists held beliefs that such contaminated sharing of the same drinking water sources contributed to transmission of MCF. These views are supported by a study by Swai et al. (2013) who established that the Malignant Catarrhal Fever (MCF) can be transmitted from wildebeest to cattle via ingestion of contaminated pasture, water with afterbirths materials or ingestion of hair from wildebeest calves, or through aerosol.

Acquisition of water by men and women

The household interviews showed that the majority 347 (87.6%) of the respondents reported that women were being involved in almost all domestic duties such as caring for families, hut construction, and loading and unloading donkeys. The results reflect the situation in most African cultures where women play different roles in the societies compared to men and they do not have a say in the societies. Njenga et al. (2021) and that of Mlekwa (1996) stated that women fetched water, firewood, manufactured skin clothes, bed coverings, prepared bead ornaments and necklaces, kept milking gourds clean, and milked cows. These responsibilities exposed women to drinking water from dirty sources and the risks of fetching water far more than men add the possibility of contracting waterborne diseases such as skin infection. It was reported that 103,463 people (47,825 men and 55,638 women) in NCA were hospitalized due to waterborne diseases such as diarrhea, worms, skin infection, typhoid, dysentery and cholera from 2015 to 2019 (URT, 2019). The implication of these results is that intervention in water resources management should not focus on men while ignoring the women category.

Community response to availability of tap water

Almost all 367 (92.7%) of the respondents complained about the long distance travelled from where tap water is installed to their residences. As previously explained, the installation of tap water in the NCA is unfriendly to the communities as it involves walking for a few meters up to 10 Kms depending on the location of a school or dispensary. Most tap water is installed in social provisional service areas such as schools and dispensaries as opposed to community areas. The distance differs from village to village or from where tap water was installed to community residences. Long distance from the installed tap water to another tap water was done purposely as the area is not allowed to develop heavy infrastructure services. The establishment of more social services could trigger an influx of human population.

Figure 5: Sharing of drinking water sources by human, livestock, and wildlife
Source: Field Survey, 2022

Figure 6: The effects of MCF to livestock
Sources: Cosmas, 2022

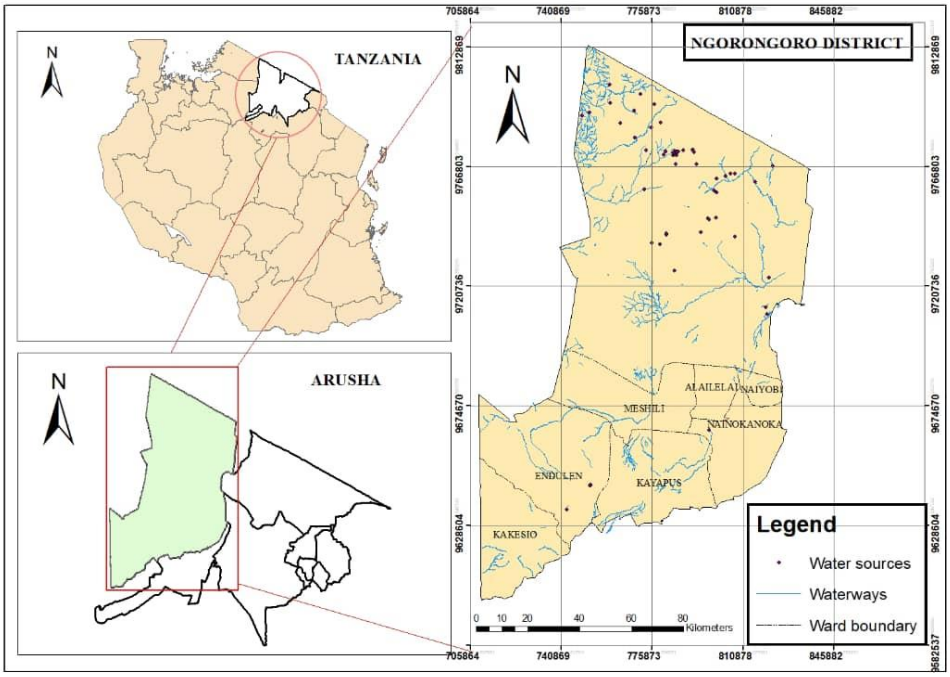

Figure 7: Map of the NCA showing the distribution of drinking water sources

Figure 8: Humans and livestock sharing stream water
Source: Cosmas, 2022

Community views on scarcity of drinking water

Most of the interviewed respondents 372 (93.9%) reported scarcity of drinking water sources for humans, livestock, and wildlife in the NCA (Figure 7). The population increase coupled with the effects of climate change have led to prolonged droughts, water scarcity and competing water usage among humans, livestock, and wildlife leading to transmission of diseases. The spread of anthrax and tuberculosis in the NCA is associated with the sharing of drinking water sources among humans, livestock, and wild animals.

Carlson et al. (2019) established that livestock and people in the world are at risk of anthrax spores due to exposure to contaminated pasture, soil and water. Mkiramweni et al. (2016) concur that pastoralist communities residing in NCA consider water scarcity as a major problem for human and livestock uses. The absence of well-supplied water systems has forced the communities to use limited and unsafe water, thereby causing transmission of diseases.

Discussions with key informants and field observation confirmed that there was scrambling for water caused by sharing of drinking water from single sources (Figure 8).

Community views regarding availability of latrines

The household interviews showed that 90.2% of the respondents reported the absence of latrines in almost all the villages in the NCA. The pastoralist communities are characterized by nomadic lifestyles which do not encourage building of latrines. The nomadic lifestyle forces the pastoralist communities residing in NCA to defecate in bushes near their residence's consequently causing pollution of drinking water sources. UNICEF/WHO (2015) reports revealed that human excreta polluted drinking water affecting 0.7 billion people worldwide who have no access to safe drinking water. Pollution of drinking water caused by sharing among humans, livestock and wildlife occur during rainfall or storms when the human waste drains into drinking water sources. The eruption of cholera in NCA in 2018 had pervasive effects on the pastoralist communities affecting 1,572 people, leading to a loss of life of 22 people due to pollution of drinking water sources. Defecation in bushes is common in many parts of Sub-Saharan Africa resulting in pollution of drinking water sources. A study by JMP (2008) reported that twenty-eight percent (28%) of Sub-Saharan African populations defecate in the open while 23% use makeshift sanitation facilities with low hygiene standards.

FGDs indicated that men pretended not to defecate in bushes. This pretense is attributed to cultural beliefs surrounding shame of defecating imparted on young children. Women and youngsters were found to have different places in the bush reserved for defecating compared with men.

"The community is not accustomed to the use of the latrines. They believe that it is shameful for old men to be discovered to have defecated in the bushes. They normally get up early in the morning and walk far away in the forest to defecate out there. The bush used for old men defecation is prohibited to be used by the rest of the families. Women also defecate in the bush but in different areas from where the youth defecate.".

Source: Narration of the respondent in Kayapus village during FGD

Field visits revealed that rainfall acted as the transporting agent of fecal wastes of humans and animals to drinking water sources. The contaminated drinking water sources were used by humans and livestock for drinking, and only cooking while bathing were used by humans only.

Potential waterborne diseases

The respondents were asked to mention potential waterborne diseases occurring in NCA. The Maa language was used to identify these diseases. The reported diseases were elototo *engoshoko*/ (diarrhea); emoyan *elototo engoshoke engurhuma*/ (cholera); *emoyan olnjoni* (skin infection); *eyarata engosheke orsage* (dysentery); olkurto (worms) and *emoyan engare torono* (typhoid fever). About 265 (66.9%) of the respondents interviewed reported diarrhea as the leading waterborne disease in the NCA, 55 (13.9%) cholera" 22 (5.6%) skin infection; 21 (5.3%); dysentery 19 (4.8%); worms and 14 (3.5%) typhoid fever (Table 4).

The Maasai pastoralists in NCA were found experiencing the effects of waterborne diseases due to the sharing of drinking water sources among humans, livestock, and wildlife. Studies carried out by Mellou et al. (2014) and that of Shamsu-Deen (2013) reported that the quality of water is known to be a transmission path for infections, diarrhoea and other diseases. Furthermore, studies carried out by Chigor et al. (2012) and that of Odjadjare et al. (2010) revealed that pathogenic microorganisms such as bacteria, protozoa and viruses originating from fecal sources like wastewater treatment plants or animals might pollute surface water.

Table 4: Waterborne diseases in NCA

Variable	Frequency	Percent (%)
Diarrhea	265	66.9
Cholera	55	13.9
Skin infection	22	5.6
Dysentery	21	5.3
Worm	19	4.8
Typhoid fever	14	3,5
Total	**396**	**100**

Source: Filed Survey, 2022

People affected by cholera in NCA

During questionnaire interviews and discussions with key informants, it was reported that cholera was frequent and widespread in almost all the villages in NCA (Figure 9).

During field visits and interviews with medical officers, it was recounted that the available drinking water sources were contaminated by bacteria resulting in the transmission of waterborne diseases such as dysentery. With regards to the prevalence of waterborne diseases in the NCA, the communities were supplied with tools for storing water with medication for treating water to combat bacterial or virus infection linked to drinking water sources.

"We supplied buckets and water guards to the communities to treat the water which they were using. They received and then threw them away because they were not ready to use the treated water. They were risking their lives due to cohabitation which might cause various diseases since the livestock and wildlife were bacteria and virus careers".

Source: A complaint from medical officer at the NCA hospital during the interview.

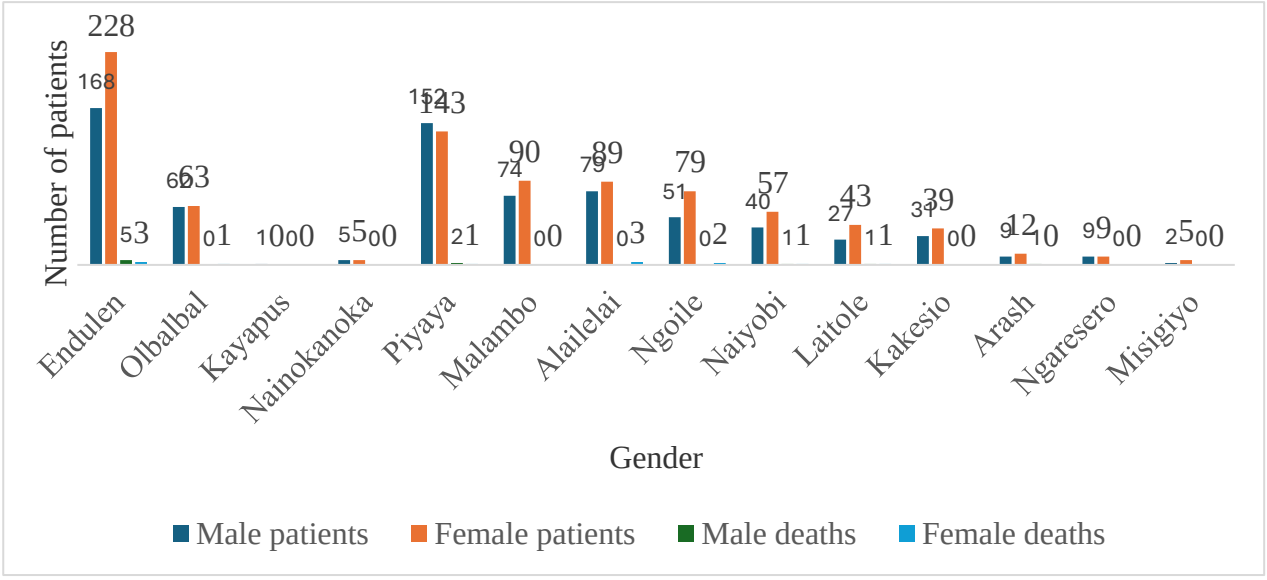

Figure 9: Number of males and females affected by cholera
Source: Demographic Health Surveys (DHS)

Drinking water sources and anthrax

During the interviews and discussions with the key informants, the researcher was informed that the anthrax disease has been recurring in NCA. Results (Figure 10) displays that anthrax recurred and spread in almost all the villages. Data collected over a period of four months indicated that 59 people (26 men (44%) and 33 women (56%)) in the pastoralist community suffered from anthrax. The prevalence of anthrax in the NCA is associated with shared drinking water sources among humans, livestock, and wildlife. The transmission of infectious diseases could be through a non-biological physical vehicle such as soil or water (Van Seventer and Hochberg, 2017; Carter and Tibbett, 2008). The prevalence of waterborne diseases including anthrax in NCA was a major concern following a diagnosis study of water quality for human consumption done in a water laboratory in Singida region, revealing fecal coliform and total coliform bacteria in the water sample. The laboratory tested parameters have shown the presence of Faecal Coliform and Total Coliform (URT, 2021). This suggests that, apart from fecal bacteria, there were other bacteria present in the drinking water sources.

During the field observation and discussions with key informants, the study revealed the effects of anthrax on wildlife and humans (Figure 11).

People hospitalized after drinking water from polluted water sources 2015-2019

The interviews and discussions with key informants revealed the number of people who were hospitalized in connection to drinking water sources from 2015 to 2019 in NCA. Results (Figure 12) shows that about 61,730 people (28985 males (47%) and 32745 females (53%) were hospitalized due to diarrhea followed by worms affecting 17,195 people (7937) males (46.2%) and 9258 females (53.8). Of these, 53.8% had skin infections, while 12,336 (5852 males (47%) and 6484 females (53%) had typhoid; 8,233 people (3307 males (40%) and 4,926 females (60%) had dysentery; 2,449 (1034 males (42%) and 1415 females (48%), and cholera 1,572, of which 710 were males (45%) and 810 were females (55%). Based on these results, women were more vulnerable compared to men. This could be partially explained by the roles played by women in the communities as they involve in fetching water for the families hence keeping them in constant contact with drinking water sources. Adult females are more susceptible and are the leading people to be hospitalized compared to males due to diarrheal infections resulting from using unsafe water sources (Tornheim et al. 2010).

Furthermore, the study confirmed that 103,463 people (47,825 males and 55,638 females) in NCA were hospitalized due to waterborne diseases such as diarrhea, worms, skin infection, typhoid fever, dysentery and cholera from 2015 to 2019 (URT, 2019). These were cases reported to hospitals, but they could be cases which were not reported since these communities tend to use traditional herbal medicines to treat patients at home. As observed by Laiser (2013) and Mlekwa (1996), religious powers are entrusted to the *'laibon'*, a ceremonial skilled person who protects people from disease and bad luck, treating diseases and executing rainmaking ceremonies. Failure of the communities to report to hospitals has made it difficult to mitigate diseases caused by drinking water from polluted water sources.

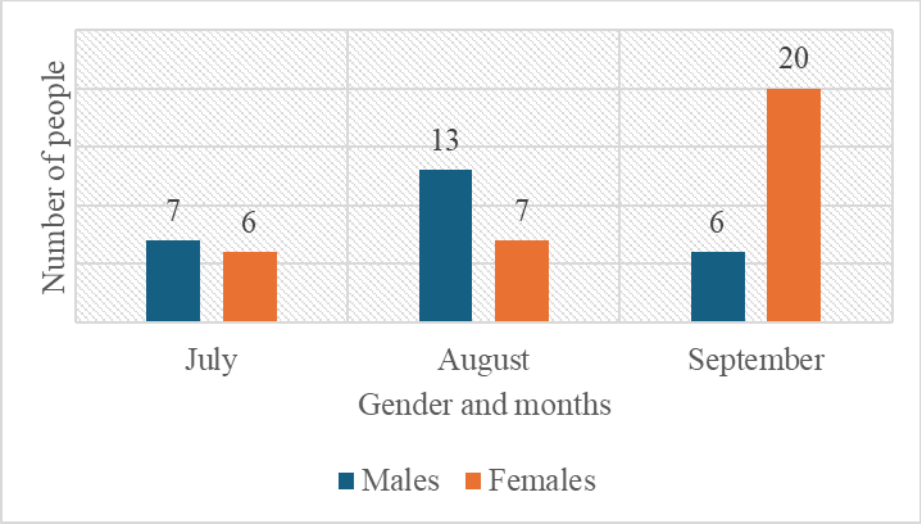

Figure 10: Number of males and females affected by anthrax in three months
Source: Demographic Health Surveys (DHS).

Figure 11: The wildlife and human affected by anthrax
Source: Kilasi, 2022

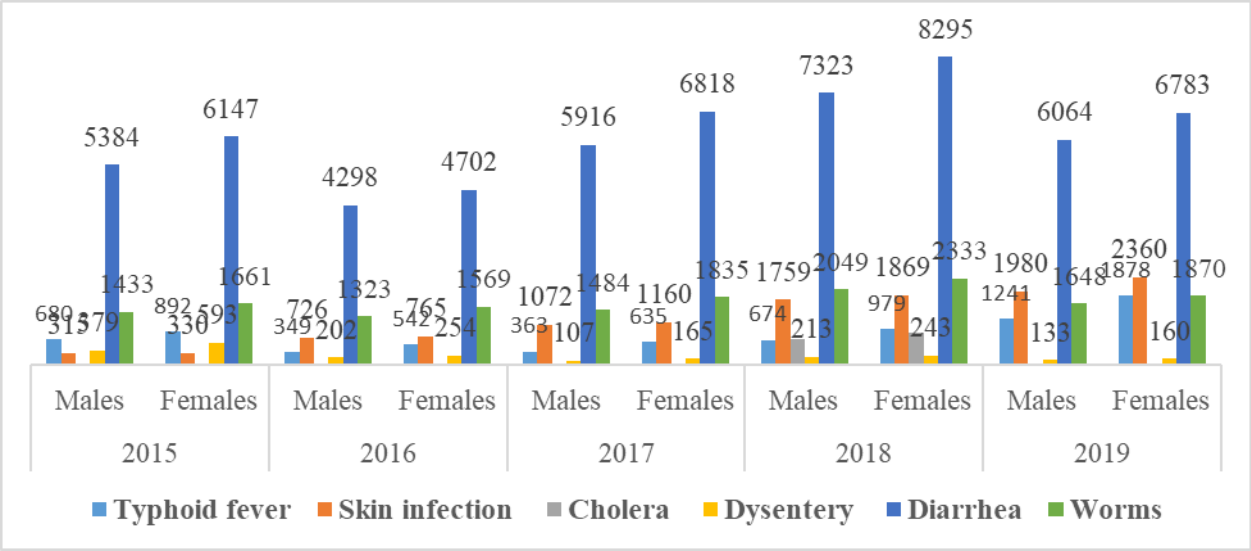

Figure 12: People hospitalized due to waterborne diseases 2015 to 2019
Source: Demographic Health Surveys (DHS).

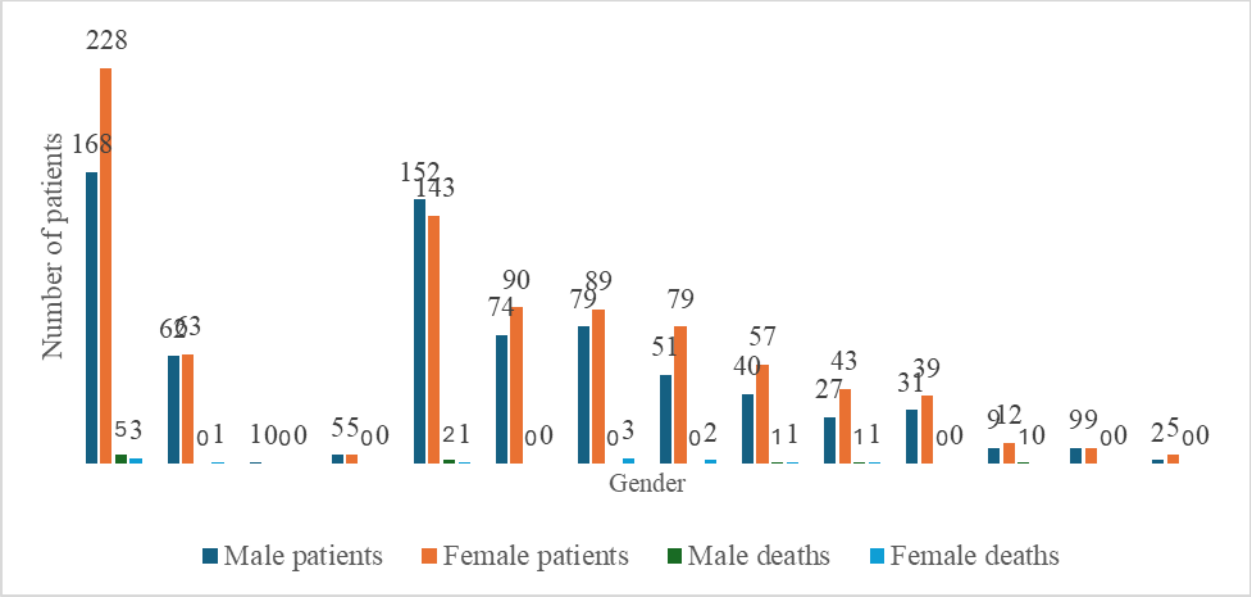

Figure 13 shows number of men and women affected by cholera.
Source: Demographic Health Surveys (DHS).

Challenges posed by waterborne diseases

Figure 13 indicates that 1,572 people (710 males (45%) and 862 females (55%) suffered from cholera in NCA based on the data collected in 2018. Notably, women were more susceptible to waterborne diseases in the NCA compared to men. This is attributed to the fact that women are more directly involved in performing all domestic activities such as fetching water. These social-cultural roles make them more frequently contact and interact with other competing water resources users (wild animals) struggling for drinking water. This is confirmed by the contention that women are the direct victims of diseases transmitted from drinking water sources since they are the primary caretakers of the children, elderly, disabled family members, and perform cleanliness at home such as house wash (Fisher 2008; Halvorson 2004).

Conclusion and Recommendations

The results of this assessment have shown that unfiltered waterholes shared among humans, livestock and wildlife is the main source of disease transmission. Other sources for transmission of diseases were the use of untreated tap water, rivers, spring water and rainwater. The factors influencing the use of unfiltered waterholes are limited access to tap water, scarcity of drinking water sources, drought, population and tourists increase. The sharing of water coupled with lack of latrines impacted fecal contamination of drinking water sources. In sum, women are more susceptible to waterborne diseases than men since they are relatively more directly involved in performing all domestic activities including fetching water. Potential waterborne diseases affecting pastoralist communities are diarrhea, cholera, skin infection, dysentery, worm, and typhoid fever.

To mitigate the adverse impacts of drinking water from polluted water sources which impact disease transmissions, the following points are recommended: First, increasing the establishment and distribution of tap water closer to residents' houses to avoid sharing with wild animals, thereby lessening transmission of diseases; Secondly, to encourage the communities to use treated water with water guard or boiled water. Third, sensitizing the communities to possess and use latrines which could avoid defecating in bushes. Fourth, measures should be taken to control the population increase by encouraging larger populations to relocate to other areas in order to maintain ecological balance with the available resources and avoid competition over the scarce resources in NCA. Fifth, education provision to pastoralist communities on the aspect of disease transmission is recommended. Sixth, the study suggests the development of many water sources to combat water scarcity closer to community locations to reduce unnecessary water sharing. Seventh and finally, the paper recommends a need for social justice, particularly through upholding women oppressive gender roles which make them more vulnerable to waterborne diseases.

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Authors' contribution
The first author (Oswin F. Linuma): drafted the manuscript and collected the data. Anesi S. Mahenge, Rubhera R. A. M. Mato, and Alex D. Greenwood reviewed, edited, and made recommendations for further improvement of the manuscript. All authors read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate
The study obtained ethical clearance from the Ardhi University; the 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. Confidentiality was also assured before conducting the interviews. In addition, the final manuscript was read and approved by the National Institute for Medical Research (NIMR), 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.

Conflicting interests
All authors have declared that they have no conflict of interest.

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