Rainfall variability and socio-economic constraints on livestock production in the Ngorongoro Conservation Area, Tanzania

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Abstract

Rainfall variability is of great importance in East Africa, where small-scale farmers and pastoralists dominate. Their livestock production activities are heavily dependent on rainfall. We assessed pastoralist perceptions on climate change, particularly rainfall variability, its impact on livestock production, and the adaptive capacity of pastoralists in the Ngorongoro Conservation Area (NCA), Tanzania. We combined 241 household interviews and information from 52 participants of Participatory Rural Appraisal (PRA) with archived data from the Ngorongoro Conservation Area Authority (NCAA). We found that most (71%) pastoralists were aware of general climate change impacts, rainfall variability, and impacts of extreme events on their livestock. Most ($> 75\%$) respondents perceived erratic and reduced amounts of rainfall, prolonged and frequent periods of drought as the main climate change challenges. Mean annual rainfall accounted for only 46% (R^2 , $p=0.076$) and 32% (R^2 , $p=0.22$) of cattle, and sheep and goat population variability, respectively. Unexpectedly, cattle losses intensified by 10% when herd size increased ($p<0.001$) and by 98% ($p=0.049$) when mobility increased, implying that increasing herd sizes and mobility do not cushion households against climate change shocks. Our study highlights the need to enhance adaptive capacity of the pastoralist communities through interventions that proactively reduce vulnerability. We recommend that future research should address the profitability of pastoral cattle production under changing environmental conditions.

Keywords Climate variability · Pastoralist perceptions · Rangelands · Eastern Africa · Adaptive capacity

1 Introduction

Rainfall strongly influences human life styles and land use patterns [1, 2]. As such, areas receiving at least 700 mm of annual average rainfall are likely to be dominated by rain-fed agricultural activities, whereas areas with low and/or highly variable rainfall regimes are dominated by pastoralism as the main livelihood strategy [3]. The rural

underprivileged pastoralists in developing countries are, therefore, the most exposed to the effects of climate change and rainfall variability [4]. In East Africa, rainfall variability has evident wide ranging effects and its devastating impacts are agreed upon by researchers and policy makers, while the extent of exposure differs locally [5, 6].

As rainfall becomes more variable, plant tissues increasingly lignify, have lower digestibility [7], and change in

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composition towards less palatable species [8]. These shifts may lead to land cover/land use changes that comprise less favourable compositions of animal forage species, making it more difficult for smallholders to manage feed deficits in the dry season [9]. Livestock die offs have become increasingly common [9, 10], which implies the necessity of an in-depth study on the effects of rainfall variability on traditional cattle pastoralism and household food security.

For many years, pastoralists have diversified their herding strategies and management techniques to cope with climate and environmental dynamics [11]. They have diversified their livestock species, expanded grazing/browsing sites to larger areas and rotated the use of dry and wet season pastures [12]. In addition, pastoralist families usually comprise many members to provide labour for facilitating herd mobility [13]. Furthermore, pastoralists maintain large herds to ensure that sufficient animals survive to rebuild the herds after drought [14]. However, this combination of adaptation strategies has become constrained by a number of factors, including an increasing human population along with a stable/declining livestock population and a decreasing rangeland area available [15, 16].

The Ngorongoro Conservation Area (NCA) is a multiple land use area, established in 1959, encompassing both wildlife conservation and economic development of resident Maasai pastoralists in Tanzania [17]. The NCA illustrates, on a rather small scale, many of the biological constraints and responses characterizing rangelands and pastoralism in East Africa, balancing the competing needs of its multiple users [18]. The NCA is currently facing climate change-driven challenges [19], high human population growth rates [20], and wildlife-livestock competition attributed to localized overgrazing [21]. A large proportion of the NCA is semi-arid, with an average annual rainfall of less than 500 mm; hence, grassland productivity is low and the risk of overgrazing and death from starvation is high [22].

We wanted to (1) document the perception of the NCA pastoralists towards rainfall variability and its impacts on their traditional pastoral livelihoods and rangeland conditions. Further, we (2) explored the trends in livestock production and herd sizes to portray rainfall variability as one of the drivers of livestock dynamics; and, (3) analysed the drought adaptation strategies in NCA pastoralists. We expected that pastoralists will perceive reduced lengths of rainfall seasons and more frequent droughts as the main indicators of rainfall variability [23]. Furthermore, drought incidents will be reflected by massive cattle die off, but will be less visible for sheep and goats, similar to what has been recorded in Ethiopia [24] and South Africa [25]. We also expected that the mean livestock mortality rates will decrease with intervention measures (supplemental food

and mobility) [26] and demographic variables (herd and household size) [13].

2 Materials and methods

2.1 Study area

We conducted this study in four wards of the Ngorongoro Conservation Area (NCA) in northern Tanzania, 3° 14' 29.56" S and 35° 29' 16" E, a UNESCO World Heritage Site, predominantly inhabited by the Maasai pastoralists [27]. Rainfall in NCA is highly seasonal and variable, with the eastern slopes of the crater highlands receiving annual averages of about 1200 mm, which decreases to about 800 mm in the midlands and further to 400 mm on the plains of the lowlands [22]. Traditionally, the Maasai are semi-nomadic pastoralists and their main economic activities in the NCA are livestock keeping and tourism [28]. The livestock species included cattle (*Bos taurus*), goat (*Capra aegagrus hircus*), and sheep (*Ovis aries*) [29]. The four wards (Fig. 1) were selected based on elevation and variations in rain intensity and, hence, rangeland productivity; Endulen (Midland), Nainokanoka (Highland), Olbalbal (Lowland), and Ngorongoro (Midland) [29].

2.2 Data collection

Data collection involved (1) participatory discussions (2) household surveys using semi-structured interviews [30] and (3) acquisition of long-term rainfall data of the study area, covering monthly and average annual rainfall (mm), recorded at the Ngorongoro Conservation Area Authority (NCAA) Headquarters, from the years 1967–2018. Participatory Rural Appraisal (PRA) meetings were conducted in each of the four wards with eight to twelve participants [31] in March, 2018, to elicit information on the understanding and perception of village leaders/elders and livestock officers about the trends in climate incidents (particularly rainfall events) over the last ten years. In addition, we asked about perceived changes in rangeland condition, grazing mechanisms/initiatives to adapt to changing rainfall patterns and the interest and influence in conservation initiatives by different groups. All participants were formally invited by the Ward Executive Officers (WEO) in advance of the group meetings. A checklist was used to facilitate the discussions. All discussions were conducted in Kiswahili language, audio-taped and transcribed into English.

We further administered 241 household questionnaires across the four wards between March and June, 2018. The household surveys were conducted by the researcher and two local research assistants, who had been trained

Fig. 1 Map of Ngorongoro Conservation Area in Northern Tanzania showing the four wards selected for this study

in survey techniques. All individuals interviewed during our survey were household heads that had lived in the area for at least 10 years and were randomly chosen from the village household list using a random number generated table in excel. We asked respondents to answer questions regarding trends in rainfall, drought frequency, pasture availability, rangeland cover, water availability, and livestock production. We also collected data on socio-demographic characteristics of the households, including

livestock numbers and constraints to livestock production. We further asked about herd mobility and intervention measures taken to reduce the impact of droughts and associated livestock mortalities.

2.3 Statistical analyses

Descriptive analysis for the structured (closed) household questionnaire was performed using frequency tables. Using

the rainfall data, the Standardized Precipitation Index (SPI) was calculated using the SPI package in R version 3.1.6 [32]. This index reflects the number of standard deviations, by which the observed cumulative rainfall departs from the long-term mean and is considered an appropriate method for monitoring droughts in East Africa [33]. Monthly precipitation time series were also aggregated annually and in monthly trimesters as December–January–February, March–April–May, June–July–August, and September–October–November, which correspond to short dry, long rain, long dry, and short rainy season, respectively, to observe potential changes at the seasonal scale. HydroTSM package [34] in Rstudio was used because of its capability functions in the management, analysis, interpolation, and plotting of time series from daily and monthly data.

Livestock production was analysed from the number of livestock owned by households and complemented by livestock data based on NCAA archived data spanning from the years 1967–2017. We assessed the change in proportion between cattle and sheep and goats over that time period. To quantify the different livestock types and sizes, the Tropical Livestock Unit (TLU) was used, with 1 TLU = one cow with a body weight of 250 kg. The commonly used TLU in eastern Africa is cattle = 0.7, sheep = 0.1, goat = 0.1, pig = 0.2 and chicken = 0.01 [35]. Regression analysis in Minitab was used to determine associations between livestock populations and rainfall variability.

A logit model was used to identify factors influencing cattle deaths during the 2015–2016 dry period using the variables “number of cattle owned before drought”, “supplemental feeds” and “household size”;

$$\log[P_{ij}/(1 - P_{ij})] = \gamma_0 + \gamma_1 x_{1j} + \gamma_2 x_{2j} + \gamma_3 x_{3j}$$

where P_{ij} is the probability of death of cattle in a herd belonging to the j household ($P_{ij} = 1$ for death observation and 0 otherwise), γ_0 is the intercept, γ_1 to γ_5 are regression coefficients, x_{1j} is the pre-drought cattle herd size, x_{2j} is the family size, x_{3j} is feed supplementation ($x_{3j} = 1$ for supplemented herds and 0 otherwise). For herds that experienced mortalities during a drought, mortality rate was calculated as the number of dead cattle divided by the number of cattle owned before the drought year. A generalized linear model (GLM) with Poisson distribution was further used to identify factors influencing variation in mortality rate.

Table 1 The proportion (%) of pastoralists that perceived changes in climate and rangeland condition in the Ngorongoro Conservation Area (NCA) ecosystem over the last 10 years ($n = 241$)

Variable	Decrease	Increase	No change
<i>Climatic conditions</i>			
Precipitation	4	79	17
Length of rainy season	61	11	28
Flood occurrences	15	21	64
Drought occurrences	16	76	8
<i>Rangeland condition</i>			
Time spent for finding good grazing land	14	63	23
Availability of grazing land	50	30	20
Grassland vegetation cover	60	21	19
Grass species diversity	62	34	4
Shrubland cover	3	73	23

3 Results

3.1 Rainfall patterns and variability

The study area had a bimodal rainfall characteristic with mean ($\pm$ SD) monthly rainfall of 73.5 ± 84.3 mm over the years from 1967 to 2018 (Fig. S11). The Standardized Precipitation Index (SPI) showed prolonged periods of moderate dry weather ($-1.29 \leq \text{SPI} < -0.80$) recorded in 1995/1996 and 2015/2016 and exceptionally dry weather ($\text{SPI} \leq -2$) recorded in between 1991 and 1998 and between 2012 and 2016 (Fig. S12). The mean precipitation varied from 0 to > 300 mm per season over the study period (Fig. S13). The highest annual mean precipitation (≥ 300 mm) was recorded in the long rainy season of the year 1983, and similar amounts were recorded in 1997 during the El Niño effect. The short rainy season had its highest mean precipitation (150 mm) in 1969, which happened only once in the entire period of 50 years, while the period between 2015 and 2016 presented instances of lowest values of precipitation. Hence, rainfall variability occurred within the season, from season to season, and from year to year.

3.2 Herders' perception on rainfall variability and rangeland condition

More than two-thirds (71%) of the respondents were aware of recent changes in rainfall patterns and increased frequency of droughts, floods, and disease outbreaks. They identified human land-use activities such as deforestation, desertification, and improper grazing practices as the main factors impacting rangelands. Majority (79%) of pastoralists claimed that the amount of rain per season has increased over the last ten years, but rainfall events had become more unpredictable and shorter in duration

as summarized in Table 1. Most respondents (76%) also perceived an increase in drought frequencies.

About two-thirds, i.e. 63%, and 73% of the 241 respondents, mentioned that they need more time for finding good grazing areas and that shrubland cover has increased over the last ten years, respectively. More than half (50%, 60%, and 62%) of the respondents mentioned a decrease in availability of grazing land, grass cover, and grass species diversity, respectively. Drought was mentioned as the likely cause of decrease in grazing land by 21% ($p=0.01$), while the remaining factors such as increase in human and livestock population remained less important.

3.3 Livestock production

All 241 surveyed households owned some livestock, the mean ($\pm$ SD) TLU owned per household was 28 ± 21 but varied from 3 to 140 TLU (Table S11). In particular, 68% of pastoralists mentioned cattle as the most vulnerable livestock type, that the number of cattle per household has been declining, and that cattle were generally in poor condition. Despite of the recurrent rainfall variability, the proportion of sheep and goats has increased by 54% and 63%, respectively (Fig. 2), highlighting the preference by pastoralists to own smaller livestock types.

Our NCAA archived records showed that the number of cattle was about 161,034, whereas the number of sheep and goats was 100,689 at the time of establishment of NCAA in 1960s, summing up to a TLU of 79,617 and a per capita TLU of 10. The observed decreasing trend of TLU is mainly associated with the increase in human population, which has further reduced the TLU to 1 in the year 2016. Moreover, we found that from the time of establishment of NCAA, there has been an overall steady increase in the number of people ($R^2=0.96$, $p<0.001$), sheep and goats ($R^2=0.71$,

$p=0.002$) and cattle ($R^2=0.55$, $p=0.028$), whereas the TLU per capita steadily decreased ($R^2=-0.7$, $p<0.003$), (Fig. S14).

3.4 Effects of rainfall variability on livestock population and mortality

The mean annual rainfall of NCAA accounted for only 46% ($p=0.076$) and 32% ($p=0.22$) of cattle, and sheep and goat population variability, respectively. Moreover, during the 2015/2016 drought occurrences, 112 herds (47%) of the interviewed 241 pastoralists experienced cattle losses. The likelihood of cattle death occurrences increased by 10% ($p<0.001$) and 98% ($p=0.049$) with an increase in number of cattle in the herd and increased mobility, respectively (Table 2). Mortality rate barely decreased, by 2% ($p=0.116$) and 2% ($p=0.697$) with increasing number of cattle in the herd and household size, respectively. Feeding cattle with supplementary feeds and mobility did not significantly reduce the odds of death occurrences, i.e. by 22% ($p=0.57$) and 15% ($p=0.76$), compared to those receiving no feed supplementation (Table 2). It was difficult to quantify the amounts of the different feed types purchased and to assess their sufficiency for the target animals because pastoralists have no tendency of keeping records of livestock feeds.

4 Discussion

We found that pastoralists were aware that climate change and variability is happening in their local areas and the impacts were felt in their major form of livelihood strategy. Similarly, the PRA discussions (Annex 1) revealed that declines in amounts of rainfall, delayed rainfall starting points, and early cessation of rainfall have become more frequent within the last decade. Similar perceptions were reported by pastoralists in other semi-arid rangelands [36–38] as well as by farmers in the southern highlands of Tanzania, western and southern Africa [39–41]. Respondents admitted that frequent droughts have led to severe economic impacts associated with poor livestock markets and claimed that the price of cattle kept on declining due to poor health condition. Moreover, respondents reported that inadequate feed resources and water as well as heat stress has led to reductions in milk yield, which was also reported elsewhere in Tanzania [42]. Milk is a staple food for pastoralists, and a reduced supply may pose risks to food and nutritional security in these communities, in particular for women and children [11]. Hence, our study calls for improvements to adaptive capacity of pastoralist communities, including effective and sustainable animal health services.

Fig. 2 Average ($\pm$ SE) number of livestock owned per household in the surveyed villages of the NCAA over the last 10 years (based on interviews). Livestock is based on TLU (1 TLU = one cow with a body weight of 250 kg)

Table 2 Factors affecting death occurrence and extent of mortality rate in cattle herds for the year 2015/2016

Predictor variables	Mean ^a	Death occurrence ^b		Mortality rate ^c	
		Odds ^e ratio	<i>P</i>	Estimated coefficients	<i>P</i>
Number of people HH ⁻¹	7.7	−0.003	0.966	−0.022	0.697
Pre-drought cattle numbers HH ⁻¹	20.4	0.101	<0.001	−0.021	0.116
Feed supplement (yes/no) ^d		0.182	0.691	0.219	0.576
Mobility (yes/no) ^d		0.984	0.049	0.148	0.762

Death occurrence based on the full number of surveyed households ($n = 241$). Mortality rate based on the number of households that experienced deaths ($n = 112$), HH = household

^aMean for quantitative variable

^bPresence or absence of death

^cProportion of number of deaths at household level to pre-drought herd size

^dDummy (indicator) variables

^eOdds ratio greater than 1 indicates that death is more likely to occur, and an odds ratio less than 1 indicates that death is less likely to occur

4.1 Climate variability information

The concept of 'climate change' was associated with variability in weather parameters, the major concern being erratic, and unpredictable rainfall, which is a typical pattern of conception in communities living in arid areas [10]. Analysis of rainfall data collected from NCAA headquarters shows a slight overall decline in rainfall over the years from 1967 to 2018. Moreover, pastoralists were able to recall years, in which they experienced severe water and pasture shortages, which correlated with NCAA rainfall data, i.e. two incidents aligned with years of low total precipitation and/or extended periods of moderate droughts, as indicated by the SPI and the time series of seasonal precipitation. A decline in overall rainfall and increased variability is a current concern over a wide range of similar communities across Africa and has been reported in other regions of Tanzania and eastern Africa [42, 43]. This condition has severely impacted availability of water and pasture and is likely to lead to conflicts over rangeland resources between pastoralists and wildlife management authorities, as was reported in Monduli [44], Kilombero [45], Burunge [46] and many other places in Tanzania, where pastoralism represents the main livelihood basis.

4.2 Impacts of climate change on livestock production

Impacts of rainfall on livestock production have often been expressed as a drastic decline in livestock population in the years following drought incidents [23, 47]. In our study, pastoralists reported that recurrent drought periods have caused massive losses of livestock, in particular cattle. Droughts have led to severe feed shortages and water scarcity, which leads to serious socio-economic

impacts [48]. For example, Borana of Southern Ethiopia faced high cattle losses of up to 37% and 42% of all cattle during severe drought periods in 1983–1985 and 1991–1993, respectively [49]. Similarly, during the 2017's drought, NCAA reported to have lost 77,389 heads of cattle, 72,881 heads of goats and 78,490 heads of sheep [50], which, when compared with the livestock count of the previous year [51], translates into a total loss of about 70% of livestock. Further, droughts make animals more susceptible to infectious diseases, which reduces the ability of animals to survive [52]. Since these incidents occurred concurrently with a severe drought, which was exacerbated by a shortage of forage for livestock and wildlife, we claim that climate change might be strongly determining livestock mortality.

In our study, sheep and goat populations were moderately associated with mean annual precipitation, reflecting that smaller livestock species can survive well during good conditions [53]. Generally, cattle are the most vulnerable livestock species due to higher energy requirements than other livestock types [54, 55]. In addition, recovery of cattle populations can be prolonged by interruptions due to subsequent shocks (decline in population or disturbance in age and sex structure), which can occur under high rainfall variability [56]. Given the shorter periods between successive droughts that we observed, with an approximate interval of 4–6 years, it is unlikely that most cattle herds would have sufficient time to recover from shocks and increase to their pre-drought numbers [57].

Shifting from cattle pastoralism to multispecies herding has increased over time in response to climate change and variability [58, 59]. In our study, sheep and goats have slightly increased over the period of 10 years, while the population of cattle has decreased. This was in agreement with reports by NCAA, where a steady shift from

cattle towards small ruminant ownership was recorded, from about 8% of the TLUs in the 1960s to 26% in the present decade. This trend indicates an active selection by pastoralists towards sheep and goats, particularly in times when they need income, as it is a reasonable economic but short-term strategy for quick asset building [60]. Moreover, studies on feeding ecology suggest that sheep and goats are better adapted to nutritionally poor vegetation than cattle [61], hence, are likely to survive on a stressed environment. Studies in other parts of Africa [62, 63] also reported that changes in climate are likely to drive selection of animal species towards those that can cope best with changed environmental conditions. Sheep are an increasingly dominant livestock species in NCA, which might further degrade the rangeland vegetation due to their feeding ecology [64]. Grazing by sheep selectively removes nutritious plants and continually reduces species diversity and abundance of most vascular plants and grasses, leading to an increase in herbs, sedges and shrubs [65, 66]. Yet, the long-term impact of small stock grazing on this landscape is still uncertain, and appropriate grazing management will be required.

4.3 Livestock wealth below subsistence levels

Human population growth in NCA is estimated to be between 3 and 5% per year [67], and we found that per capita livestock holdings across households at NCA varied strongly but often was less than 5 TLU per capita. Generally, 6 TLU per capita represents a minimum adequate income requirement for pastoralists in order to meet subsistence needs [68, 69]. Below this threshold, herders must diversify their production base to provide enough food [70]. We conclude that in NCA, the majority (95%) of the households do not own sufficient livestock to sustain themselves in the traditional way and must, therefore, look for alternative sources of income. This further suggests that the human population in the NCA should be reduced and the development of non-pastoral economic activities outside NCA enhanced in order to widen the range of income generating activities and investment options available. Studies in Maasai ranches around the Maasai Mara National Reserve (MMNR) in...? reported a similar fall in per capita livestock numbers, mainly attributed to human population growth, while livestock densities had either remained the same or decreased [69].

Pastoralists in East Africa apply different adaptation strategies to reduce the impact of drought on their livestock productivity, but their overreliance on livestock makes them highly vulnerable to climate shocks [71, 72]. In our study, 34% of the interviewed 241 households had selectively supplemented weak and young animals with crop residues, straw and hay, which still could not

significantly reduce death occurrences. This fact calls for an urgent need of education to pastoralists on the importance of supplementary livestock feeding [24]. Our respondents also claimed mobility as another strategy used to cope with drought, having adapted to the vegetation heterogeneity between mountaneous forest and grasslands, which influences forage availability for grazing animals in NCA [22]. This agrees with other studies on mobility in communal rangelands of Africa [73–75].

Despite being widely practiced across Africa, mobility needs to be well planned to avoid overgrazing, range degradation, and eventually increased livestock mortality [76, 77]. A key drought retreatment strategy and an efficient way of rotational vegetation use shows an inverse relationship with mortality [13]. In contrast, our findings showed that large families did not suffer from fewer cattle losses than small families, which was also reported by Scoones [78] in Southern Zimbabwe. Moreover, in our study, large households corresponded strongly with larger herds, in which higher records of livestock deaths were inevitable. This shows that large herd sizes do not cushion households against climatic shocks, which is contrary to justifications made on the tendency by pastoralists to maximize herd sizes as a risk management strategy [79].

5 Conclusion

We found that climate variability is well understood among pastoral communities through their day to day experience and observations in NCA. Reduced rainfall and recurrent droughts were reported as major challenges to livestock production due to their impacts on pasture and water availability. Pastoralists responded to the changing environmental conditions by adjusting their herd composition towards more diverse livestock species, preferably to those with low biomass requirements. This trend underlines the need to enhance the adaptive capacity of pastoralist communities in Tanzania through interventions that proactively reduce vulnerability. Moreover, future research should address the profitability of pastoral cattle production under the changing environmental conditions.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval An Ethical clearance was obtained from the research ethics committee at the Nelson Mandela African Institution of Science and Technology (NM-AIST), Tanzania and Tanzania Commission for Science and Technology (COSTECH). Verbal consent was further obtained from all participants as reflected by their willingness to be interviewed and attend and contribute to the meetings.

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