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Effects of Temperature and Precipitation Stress on Livestock Ownership in Sub-Saharan Africa

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Abstract: Climate change threatens the livelihoods of smallholders (i.e., smallholder farmers, pastoralists, agro-pastoralists) in Sub-Saharan Africa (SSA) because of their exposure and sensitivity to the surrounding environment, including increases in temperature and changes to rainfall patterns. Scholars have argued that these environmental changes will compel crop farmers to increasingly adopt livestock because they are less vulnerable to environmental shocks than rainfed crops since livestock can be moved to access feed and water. While evidence exists that smallholders prefer different livestock species due at least in part to ecological conditions, the effects of shocks on smallholder livestock ownership in SSA remain understudied. This study investigates the impact of climatic shocks on livestock ownership in SSA using binary, ordinal, and multinomial logistic regression analyses. It finds that, under conditions of unusually high heat and low rainfall, smallholders are more likely to own livestock, more likely to diversify herds, and more likely to own smaller livestock like goats and chickens than large livestock like cattle. These findings provide important insights to help manage adversity due to climate change for vulnerable smallholders. These efforts, moreover, would be improved with more data collection and analysis.

Keywords: climate change, Sub-Saharan Africa, smallholder agriculture, livestock

Introduction

Climate change threatens the livelihoods of smallholders (i.e., smallholder farmers, pastoralists, agro-pastoralists) in Sub-Saharan Africa (SSA) because their exposure and sensitivity to the surrounding environment makes them vulnerable to changes in the ecosystem services on which they depend (IPCC, 2014; Thornton et al., 2014). These changes include increases in temperature and changes to rainfall patterns, which can have knock-on effects such as a reduction of grasslands and hence a greater reliance on woody vegetation (Liao et al., 2016; Opiyo et al., 2015). Jones and Thornton (2009) argue that these environmental changes will compel crop farmers to adopt livestock to insulate themselves from some of the effects of climate change. Because they are mobile, livestock are less vulnerable to variable rainfall and heat waves than crops, which are largely dependent on the climatic conditions where they are located – especially if households lack access to irrigation. Seo & Mendelsohn (2008) and Kabubo-Mariara (2008) found that farmers prefer different livestock in different climatological conditions, indicating that changes in climate will lead smallholders to change their livestock portfolios accordingly.

While there are studies that consider how and why farmers in SSA make the decisions they do about their livestock ownership and management in response to climate stress, such studies tend to focus on small geographic areas. To date, few studies have attempted to generalize the results of these more geographically delimited studies to a large population across the continent. Seo & Mendelsohn (2008) examine livestock choices across SSA based on long-term climatic conditions, but they do not consider how the relationships change under conditions of acute stress. Their study is also 15 years old, and the relationships between climate and livestock they investigate are worth revisiting given the changes in climate that have occurred since. To address this gap in the literature, this study takes up the following three research questions:

RQ1: How do livestock portfolios in SSA change based on heat stress?
RQ2: How do livestock portfolios in SSA change based on low-rainfall stress?
RQ3: How do livestock portfolios in SSA change based on high-rainfall stress?

I respond to these research questions using binary, ordered, and multinomial logistic regression models using a mixture of cross-sectional household data and longitudinal climate data from the Demographic and Health Surveys (DHS) dataset, accessed via the IPUMS platform (Boyle et al., 2022). Household data come from surveys taken in nine countries and climate data represent monthly temperature and precipitation measurements from the time period 1981 – 2016. The findings of these models largely comport with expectations that smallholders tend to keep more livestock species under conditions of high heat and low rainfall, especially smaller livestock like goats and chickens. These findings indicate that there could be a significant role for livestock to play in the climate change resilience strategies of smallholders throughout SSA.

Background

Some smallholders in SSA make decisions about their livestock holdings, in part, based on prevailing environmental conditions. Drought especially has been a big driver of livestock diversification (Alfani et al., 2021; Anbacha & Kjosavik, 2021; Bedelian & Ogutu, 2017; Lumborg et al., 2021; Opiyo et al., 2015; Watson et al., 2016). Other studies have demonstrated a link between climate conditions and the type of livestock households maintain. Kabubo-Mariara (2008) found that the decision to maintain goats and sheep was less sensitive than cattle to climate conditions among farmers in Kenya. The farmers were more likely to own dairy cattle at high and low temperatures (U-shaped relationship) but less likely to own dairy cattle at high and low levels of precipitation (hill-shaped relationship). Beef cattle showed the opposite relationships to temperature and precipitation, that is, farmers in the sample were less likely to choose beef cattle at higher and lower temperatures but more likely to select them at higher and lower levels of precipitation. These effects of temperature and precipitation were higher for dairy cattle than beef cattle, and the effects for beef cattle were stronger for temperature than precipitation.

The results from Seo & Mendelsohn (2008) – which draws on data from Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, and Zambia – largely comport with those from Kabubo-Mariara (2008) with some exceptions. Like Kabubo-Mariara (2008), the authors find that farmers in historically warmer areas tend to choose goats and sheep over beef cattle. They also find that as the average level of precipitation in an area increases, farmers choose to own fewer beef cattle but more chickens. However, while Kabubo-Mariara (2008) found that dairy cattle were more sensitive to climate than beef cattle, Seo and Mendelsohn (2008) find that the decision to keep dairy cattle remains largely unchanged with respect to temperature.

Changes in climate can impact livestock ownership by changing the type of feed available for browse or forage as well. Liao et al. (2016) found that social and ecological transformations in Ethiopia, including fire suppression, increasing livestock density, and climatic changes, have led to changes in the types of vegetation growing in the savannah landscape. New conditions promote the growth of woody vegetation instead of the traditional pasture that is well-suited for rearing cattle. These novel circumstances are leading pastoralists to favor camels and goats over cattle with poorer households much more likely to invest in goats and wealthier households more likely to adopt camels in addition to goats.

There are a number of other, non-environmental, reasons farmers and pastoralists choose to maintain particular types and numbers of species. Formal education (Kabubo-Mariara, 2008; Mihiretu, et al., 2019; Zampaligré et al., 2014) and knowledge of or familiarity with particular species (Cuni-Sanchez et al., 2019; Lumborg et al., 2021; Mihiretu et al., 2019; Opiyo et al., 2015; Salamula et al., 2017; Watson et al., 2016) are important factors. Other variables that affect the size and composition of livestock holdings include household size (Kurgat et al., 2020; Mihiretu et al., 2019), off-farm income (Kurgat et al., 2020; Mihiretu et al., 2019), household wealth (Anbacha & Kjosavik, 2021; Berhanu & Beyene, 2015; Leauthaud et al., 2013; Liao et al., 2016; Manoli et al., 2014; Watson et al., 2016), cultural values (Watson et al., 2016) and age (Berhanu & Beyene, 2015; Kabubo-Mariara, 2008; Salamula et al., 2017) and gender (Anbacha & Kjosavik, 2021; Kurgat et al., 2020; Musinguzi 2018; Salamula et al., 2017; Watson et al., 2016) of household members.

In order to frame this investigation, I propose a conceptual model (Figure 1) outlining the hypothesized linkages between climate stress (heat and rainfall variability) and livestock ownership outcomes. Specifically, I hypothesize that:

H1: Smallholders experiencing heat stress and low-rainfall stress will be more likely to own livestock due to increased crop failure risks.

H2: Smallholders experiencing heat stress and low-rainfall stress will be more likely to diversify their livestock portfolios to hedge against additional risk.

H3: Smallholders experiencing heat stress and low-rainfall stress will be more likely to shift livestock portfolios toward smaller, drought-resistant species (i.e., goats and chickens) to reduce vulnerability of large, water-intensive livestock.

H4: High-rainfall stress will reduce the likelihood of livestock ownership, particularly of small, drought-resistant livestock due to their burden of care (providing feed, medicine, etc.) under less vulnerable cropping conditions.

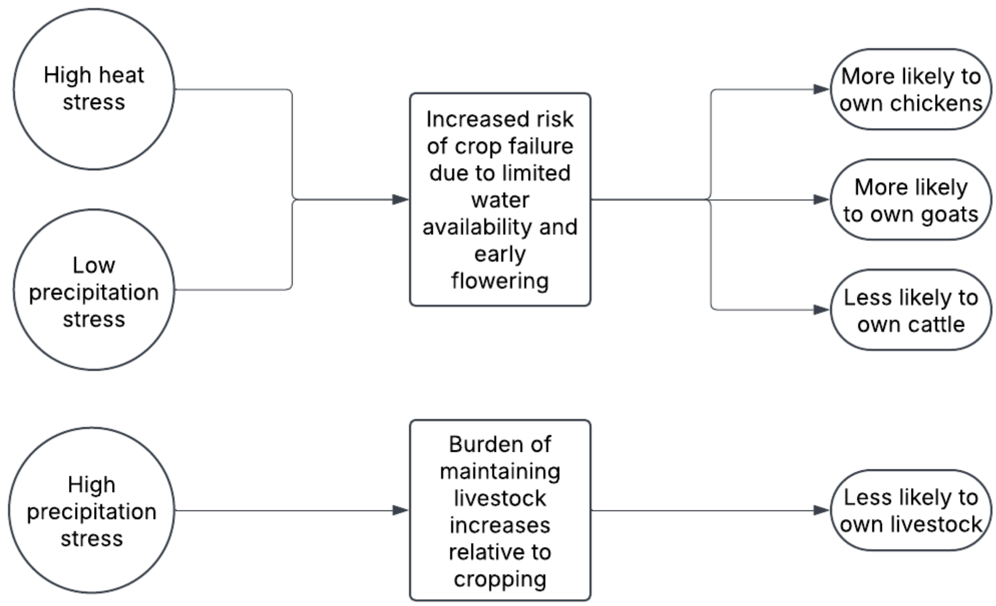

Figure 1: Conceptual model of livestock ownership under conditions of climate stress

Methods

Data

Cross-sectional household and longitudinal climate data for this analysis were obtained from the IPUMS DHS dataset (2022). This dataset is a collaboration between the Institute for Social Research and Data Innovation and the consulting group ICF. IPUMS DHS makes data from the Demographic and Health Surveys Program of the United States' Agency for International Development standardized and available for public use. Data in these surveys cover a wide range of cross-sectional and geographically coded demographic and health variables largely at the household level with some individual-level data as well. The data used for the models in this chapter cover 132,289 households and come from 15 surveys taken between 2004 and 2015 in nine countries in Sub-Saharan Africa (table **3-1**). Longitudinal climate data cover the years 1981 – 2016. The data used for this analysis were arrived at using inclusion and exclusion criteria derived from the literature outlined in the background section above. Thus, all available survey data from countries in SSA were initially included and subsequently winnowed by the availability of data on relevant variables, discussed in further detail below.

Variables

Five dependent variables were developed for this analysis: a series of binary indicators of household cattle, goat, and chicken ownership; the number of species (out of the three species just mentioned) the household owned; and a categorical herd composition variable (no livestock; household owns chickens only; household owns goats but not cattle; household owns cattle).

Additionally, six survey variables from the IPUMS DHS dataset were input directly into the logistic regression models as controls (whether or not households owned agricultural land, gender of household head, whether or not household had electricity, age of household head, number of household members, country of household) and an additional three variables were developed to include in the models (whether or not the household was in the lean season at the time of the survey, the highest education level obtained by any household member, and a wealth index based on ownership of a bicycle, television, and/or radio). Households were furthermore bound by population density. Only households classified as “rural” were included in the analysis. While the dataset does include an urban/rural variable, this variable is not consistently defined across samples. I chose, therefore, to adapt a standard of 300 residents per square mile adopted in 2020 by the United Nations Statistical commission (Eurostat, 2020). Because these density measurements are available only every five years in the dataset, I estimated density halfway between the five-year gap by averaging together the numbers on either side of the gap. I then anchored household data to the population density figure closest to the year the survey was taken. For example, if a household appeared in a sample from 2011, the population density figure used would be from 2010. Only “rural” households, or households in areas with population densities of fewer than 300 residents per square mile were included in the analysis. Households with missing data on any of the control variables were dropped from the analysis. Any additional observations from the same household (i.e., additional household members) were also dropped from the analysis so that households were not counted multiple times. These steps removed a total of 751,247 observations from the original sample (table 1). This seemingly large number of dropped observations is principally due to the dropping of additional household members from the dataset.

Climate variables were derived from temperature and rainfall data over the period 1981 – 2016. Average[1] annual high temperature in the area around the household[2] over the time period was included in the models as a control. To account for the nonlinear relationships between precipitation and livestock ownership mentioned above, average precipitation was treated as a categorical, rather than continuous, variable. This variable consists of 10 categories, made up of deciles, ranging from very low (1st decile) to very high (10th decile) average annual precipitation, based on the precipitation levels across the entire dataset. Average high temperature maintained a linear relationship with the dependent variables in the models and was thus treated as a continuous variable.

The independent variables in the models represent heat and rainfall stress. The heat stress variable was developed by first determining the average monthly high temperatures for each month across the time period from 1981–2016. A household was determined to be experiencing “stress” if average monthly high temperatures were one standard deviation above the mean for six or more months out of the year prior to the survey (Y1). To account for potential lagged effects, it was also determined whether or not stress was present in the year previous to Y1 (Y2).

[1] For all variables in this analysis, average refers to the mean

[2] Climate variables in the IPUMS DHS dataset represent average monthly high temperatures (Kelvin) and precipitation (millimeters) for a 10-kilometer circular buffer around a DHS cluster location. Each household in the samples is assigned to one of these cluster locations.

Table 1. Number of households surveyed by country and year

COUNTRY	YEAR	# OF OBS IN SAMPLE	# OF HH RETAINED	% OF FINAL SAMPLE
Burkina Faso	2010	82,095	11,533	8.72
Cameroon	2011	72,622	10,955	8.28
Lesotho	2009	44,546	7,826	5.92
Lesotho	2014	40,197	7,887	5.96
Madagascar	2008	85,858	14,024	10.6
Malawi	2004	60,747	7,598	5.74
Malawi	2010	118,850	15,802	11.95
Mali	2012	58,330	6,650	5.03
Namibia	2006	31,675	5,466	4.13
Namibia	2013	41,646	5,850	4.42
Zambia	2007	35,562	6,118	4.62
Zambia	2013	83,058	13,481	10.19
Zimbabwe	2005-6	42,698	6,320	4.78
Zimbabwe	2010-11	41,946	6,416	4.85
Zimbabwe	2015	43,706	6,363	4.81
Total		883,536	132,289	100

Rainfall stress was determined in the same manner as heat stress, but rainfall stress includes both high rainfall and low rainfall stress, i.e., one standard deviation above (high rainfall) and one standard deviation below (low rainfall) the average rainfall for six or more months out of the year. High-rainfall stress and low-rainfall stress are treated as two separate variables.

These thresholds were selected based on two key considerations. First, I sought to ensure statistical relevance and comparability. One standard deviation is a widely accepted measure of deviation from the mean and represents a meaningful departure from typical conditions without being so extreme as to significantly reduce sample sizes. Selecting a higher threshold could lead to small subsamples that undermine the statistical significance of results, while a lower threshold may not capture meaningful climatic deviations. Second, I sought a balance between severity of conditions and the analytical utility of the variable. The six-month duration was chosen as it reflects prolonged stress conditions while still allowing for sufficient variation in the dataset to compare livestock ownership patterns across different climatic contexts. This duration ensures that conditions are severe enough to plausibly influence smallholder decisions, yet not so extreme that too few households fall into each category, limiting analytical power.

The climatic thresholds were developed to test the hypotheses outlined above and were not necessarily developed to align with meteorological definitions of climate extremes. Rather, these measures serve as a practical framework for understanding smallholder responses to climatic variability. The intent is not to assert that these values define universally recognized climate stress conditions but rather to establish a transparent and reasonable set of parameters that allow for meaningful analysis. That is to say, the conditions between the groups being compared are climatically different enough to be meaningful while also retaining statistical power. These efforts are complemented by a fixed-effect variable for the country of analysis and reporting of the pseudo R^2 statistic with each table of results to indicate the models' goodness-of-fit compared to the null hypothesis.

Logistic regression modeling

Overall, I ran eight separate logistic regression (logit) models. The first three models consider chicken, goat, and cattle ownership without the climate stress variables. The next three models also consider ownership of these species but do include climate stress variables. Next, I ran an ordered logit model to consider whether households are more likely to expand the number of livestock species they own based on climate stress. Finally, I ran a multinomial logit model to consider the likelihood of particular herd compositions under climate stress. All models were weighted using the "household sample weight" as recommended by the dataset authors.

Results

Tests for multicollinearity and robustness

To ensure independence of difference in the results, I tested for multicollinearity in the independent variables (table 2).

Table 2. Test for multicollinearity

Variables	VIF	Variables	VIF
Heat stress		HH has electricity?	1.51
2nd year before survey	1.51	Age of head of HH	1.22
1st year before survey	1.64	# of HH members	1.12
both years	1.83	Country	
Low precipitation stress		Lesotho	9
2nd year before survey	1.45	Madagascar	3.29
1st year before survey	1.23	Malawi	5.57
both years	2.03	Mali	2.61
High precipitation stress		Namibia	5.03
2nd year before survey	1.14	Zimbabwe	5.94
1st year before survey	1.17	Burkina Faso	3.31
both years	1.15	Zambia	4.06
HH has ag land?	1.29	Mean temperature	5.46
Lean season?	1.57	Mean rainfall	
Gender of HH	1.17	2nd decile	2.45
Education level		3rd decile	3.18
primary	1.91	4th decile	3.24
secondary	2.07	5th decile	3.28
higher	1.35	6th decile	3.56
Wealth		7th decile	3.71
1	1.44	8th decile	3.41
2	1.73	9th decile	3.98
3	1.33	10th decile	4.86
Mean VIF	2.74		

The results for multicollinearity do not indicate cause for concern that independent variables are highly correlated. Some countries indicate moderate-to-high levels of correlation; however, this result is not unusual for a categorical variable. Given the moderately high variance inflation factor (VIF) of 5.46 for mean temperature, I chose to run a pairwise correlation test (table 3). The Pearson's correlation coefficient suggests weak to mild correlations between the climate stress variables and mean temperature. Some amount of correlation between these climate conditions is to be expected, and these results do not indicate that including mean temperature in the model is overly determinative. Finally, to ensure the robustness of the estimates, I re-estimated the model using heteroskedasticity-robust standard errors. The results remained consistent, confirming that the observed relationships between climate stress and livestock ownership are not driven by violations of homoskedasticity.

Logistic regression models absent climate stress variables

To obtain a better understanding of the data at baseline and to ensure the relevance of the control variables in the models, I first ran the binary logistic regression (BLR) models without the climate stress variables. The results can be seen in tables 4, 5, and 6. All variables held statistically significant relationships, though some levels of categorical variables were not significant, and the "lean season" variable was only significant for chicken ownership, reducing the likelihood of chicken ownership by 5%. Geography had a very strong association with livestock ownership, especially regarding cattle. Female-headed households were less likely to own all three livestock species: 9% less likely to own goats, 12% less likely to own chickens, and 36% less likely to own cattle. Higher education and having electricity in the household reduced the likelihood of livestock ownership while scoring higher on the wealth index increased the likelihood of owning livestock. The age of the head of the household did not have a very strong[3] influence on the likelihood of owning livestock, but the number of household members did have a fairly strong association. Each additional household member increased the likelihood of owning one of the three species around 12-14%. Finally, long-term climate (i.e., average high temperature and precipitation) held significant associations. For each degree increase in average temperature, likelihood of chicken ownership dropped by 3%, goat ownership by 8%, and cattle ownership by 3%. Likewise, at higher levels of average precipitation, the likelihood of owning each livestock species reduced – modestly for chickens and dramatically for goats and cattle. Households at the highest levels of precipitation are 94% less likely to own goats and 75% less likely to own cattle.

Table 3. Pairwise correlations for mean temperature, heat stress, and rainfall stress

		Mean temperature	Heat stress	Low rainfall stress	High rainfall stress
Mean temperature					
	Pearson's r	1			
	p-value				
Heat stress					
	Pearson's r	0.114	1		
	p-value	0.000			
Low rainfall stress					
	Pearson's r	0.488	0.142	1	
	p-value	0.000	0.000		
High rainfall stress					
	Pearson's r	0.079	-0.097	0.116	1
	p-value	0.000	0.000	0.000	

[3] I characterize some findings using modifiers such as "very" or "fairly." I do not operationalize these modifiers, rather, they are my qualitative interpretation of the strength of associations, especially in comparison to one another. All results are available in the tables, and I invite the reader to fact-check any wording they find ambiguous or suspicious by referencing these results.

Table 4. BLR – chicken ownership absent climate stress[4]

Variables	Odds ratio	SE	P>z
HH has ag land?			
yes	3.386	0.065	0.000***
Lean season?			
yes	0.947	0.017	0.002**
Gender of head of HH			
female	0.879	0.015	0.000***
Education level			
primary	1.123	0.022	0.000***
secondary	1.035	0.026	0.164
higher	0.759	0.035	0.000***
Wealth			
1	1.628	0.029	0.000***
2	2.344	0.050	0.000***
3	2.667	0.102	0.000***
HH has electricity?			
yes	0.316	0.009	0.000***
Age of head of HH	1.009	0.000	0.000***
# of HH members	1.139	0.003	0.000***
Country			
Lesotho	0.510	0.034	0.000***
Madagascar	1.672	0.064	0.000***
Malawi	1.223	0.052	0.000***
Mali	0.695	0.035	0.000***
Namibia	2.308	0.122	0.000***
Zimbabwe	3.237	0.149	0.000***
Burkina Faso	2.739	0.127	0.000***
Zambia	1.319	0.052	0.000***
Mean temperature	0.970	0.004	0.000***
Mean rainfall			
2^{nd} decile	0.843	0.029	0.000***
3^{rd} decile	0.908	0.037	0.019*
4^{th} decile	1.031	0.043	0.458
5^{th} decile	1.082	0.044	0.054
6^{th} decile	0.913	0.039	0.034*
7^{th} decile	0.859	0.038	0.001***
8^{th} decile	0.879	0.039	0.003**
9^{th} decile	0.759	0.035	0.000***
10^{th} decile	0.920	0.048	0.108

n = 132,289
Wald chi2 = 16371.03
P>chi2 = 0.000
Pseudo R2 = 0.160

[4] For all models: *** P<0.001 | ** P<0.01 | * P<0.05

Table 5. BLR – goat ownership absent climate stress

VARIABLES	ODDS RATIO	SE	P>Z
HH has ag land?			
yes	3.150	0.079	0.000***
Lean season?			
yes	0.994	0.020	0.780
Gender of head of HH			
female	0.910	0.017	0.000***
Education level			
primary	0.860	0.019	0.000***
secondary	0.755	0.021	0.000***
higher	0.596	0.034	0.000***
Wealth			
1	1.575	0.033	0.000***
2	2.331	0.055	0.000***
3	2.585	0.105	0.000***
HH has electricity?			
yes	0.321	0.011	0.000***
Age of head of HH	1.010	0.001	0.000***
# of HH members	1.121	0.003	0.000***
Country			
Lesotho	0.096	0.008	0.000***
Madagascar	0.039	0.003	0.000***
Malawi	0.312	0.016	0.000***
Mali	0.508	0.028	0.000***
Namibia	0.382	0.024	0.000***
Zimbabwe	0.632	0.036	0.000***
Burkina Faso	1.165	0.058	0.002**
Zambia	0.234	0.012	0.000***
Mean temperature	0.924	0.004	0.000***
Mean rainfall			
2^{nd} decile	0.506	0.018	0.000***
3^{rd} decile	0.466	0.020	0.000***
4^{th} decile	0.453	0.019	0.000***
5^{th} decile	0.370	0.015	0.000***
6^{th} decile	0.326	0.015	0.000***
7^{th} decile	0.287	0.014	0.000***
8^{th} decile	0.267	0.012	0.000***
9^{th} decile	0.143	0.008	0.000***
10^{th} decile	0.063	0.005	0.000***

n = 132,289
Wald chi2 = 16860.58
P>chi2 = 0.000
Pseudo R2 = 0.213

Table 6. BLR – cattle ownership absent climate stress

Variables	Odds ratio	SE	P>z
HH has ag land?			
yes	4.232	0.106	0.000***
Lean season?			
yes	0.986	0.022	0.523
Gender of head of HH			
female	0.639	0.013	0.000***
Education level			
primary	0.980	0.023	0.377
secondary	0.872	0.025	0.000***
higher	0.853	0.047	0.004**
Wealth			
1	1.597	0.034	0.000***
2	2.506	0.064	0.000***
3	3.022	0.131	0.000***
HH has electricity?			
yes	0.439	0.015	0.000***
Age of head of HH	1.011	0.001	0.000***
# of HH members	1.131	0.004	0.000***
Country			
Lesotho	20.115	2.085	0.000***
Madagascar	36.422	3.177	0.000***
Malawi	2.232	0.189	0.000***
Mali	63.464	5.268	0.000***
Namibia	20.404	1.763	0.000***
Zimbabwe	29.181	2.422	0.000***
Burkina Faso	116.778	9.290	0.000***
Zambia	7.784	0.620	0.000***
Mean temperature	0.974	0.005	0.000***
Mean rainfall			
2^{nd} decile	0.999	0.037	0.986
3^{rd} decile	0.974	0.041	0.528
4^{th} decile	0.911	0.039	0.031*
5^{th} decile	0.825	0.035	0.000***
6^{th} decile	0.704	0.033	0.000***
7^{th} decile	0.636	0.033	0.000***
8^{th} decile	0.328	0.016	0.000***
9^{th} decile	0.274	0.015	0.000***
10^{th} decile	0.251	0.015	0.000***

n = 132,289
Wald chi2 = 22891.08
P>chi2 = 0.000
Pseudo R2 = 0.314

Binary logistic regression models with climate stress variables

The BLR models that include the climate stress variables (see tables 7, 8, and 9) indicate that chicken ownership is likelier under conditions of heat and low rainfall stress. Chicken ownership was 10% likelier if a household experienced heat stress during Y1and 67% likelier if a household experienced heat stress for both Y1 and Y2. For low rainfall stress, chicken ownership was 12% likelier for households that experienced the stress in Y2, 15% likelier for Y1, and 29% likelier if stress was present both years. There was no statistically significant relationship for high rainfall stress.

Table 7. BLR – chicken ownership, climate stress present

VARIABLES	ODDS RATIO	SE	P>Z
Controls = yes			
Heat stress			
2nd year before survey	0.965	0.026	0.168
1st year before survey	1.100	0.020	0.000***
both years	1.667	0.035	0.000***
Low rainfall stress			
2nd year before survey	1.121	0.023	0.000***
1st year before survey	1.148	0.035	0.000***
both years	1.288	0.033	0.000***
High rainfall stress			
2nd year before survey	0.975	0.026	0.329
1st year before survey	1.002	0.026	0.926
both years	1.054	0.036	0.139

n = 132,289
Wald chi2 = 16617.52
P>chi2 = 0.000
Pseudo R2 = 0.164

Goat ownership was also likelier among households that experienced heat and low rainfall stress, though the likelihood of goat ownership decreased with extreme high rainfall stress. Goat ownership was 6% likelier if the household experienced heat stress in Y1, and 16% likelier if heat stress was experienced for both Y1 and Y2.

Curiously, households which experienced heat stress in the second year prior to the survey being taken were 22% less likely to own a goat. Households which experienced low rainfall stress in Y2 were 10% likelier to own a goat; in Y1, 12%; and in both years, 29%. Households which experienced high rainfall stress in both years were 17% less likely to own a goat.

Table 8. BLR – goat ownership, climate stress present

Variables	Odds ratio	SE	P>z
Controls = yes			
Heat stress			
2nd year before survey	0.879	0.026	0.000***
1st year before survey	1.059	0.023	0.007**
both years	1.159	0.040	0.000***
Low rainfall stress			
2nd year before survey	1.104	0.029	0.000***
1st year before survey	1.119	0.043	0.004**
both years	1.290	0.044	0.000***
High rainfall stress			
2nd year before survey	1.026	0.030	0.388
1st year before survey	1.025	0.029	0.382
both years	0.826	0.034	0.000***

n = 132,289
Wald chi2 = 17161.28
P>chi2 = 0.000
Pseudo R2 = 0.215

Table 9. BLR – cattle ownership, climate stress present

Variables	Odds ratio	SE	P>z
Controls = yes			
Heat stress			
2nd year before survey	1.018	0.031	0.559
1st year before survey	0.951	0.022	0.032*
both years	0.800	0.031	0.000***
Low rainfall stress			
2nd year before survey	1.017	0.031	0.582
1st year before survey	1.093	0.046	0.036*
both years	1.108	0.046	0.013*
High rainfall stress			
2nd year before survey	0.963	0.029	0.213
1st year before survey	1.040	0.032	0.213
both years	0.921	0.039	0.051

n = 132,289
Wald chi2 = 22807.62
P>chi2 = 0.000
Pseudo R2 = 0.314

Overall, the likelihood of cattle ownership in the BLR model is less sensitive to climate stress than chicken or goat ownership. Cattle ownership was slightly less likely if households experienced heat stress in Y1 (5%) but were much less likely (20%) to own cattle if there was heat stress in both years. For low rainfall stress, cattle ownership was more likely by 9% in Y1 and 11% for both Y1 and Y2. There was no statistically significant change in cattle ownership associated with high rainfall stress.

Ordered logistic regression model

In addition to ownership of individual species, it is important to learn whether households diversify their livestock portfolios (i.e., add additional livestock species) in response to climate stress. I thus ran an ordered logit model (OLR) to determine if the likelihood of owning more livestock species increased or decreased as a result of heat and rainfall stress (table 10).

The model found that the number of different livestock species owned tended to go up along with heat and low rainfall stress. The likelihood of owning an additional species during heat stress in Y1 went up slightly (4%) but increased greatly, to 28%, if heat stress was present in both years. As with goat ownership, there was a slight decrease (6%) in the likelihood of owning an additional livestock species if there was heat stress in Y2. The likelihood of owning additional livestock species went up for low rainfall stress in Y2 (12%), Y1 (15%), and for both years (30%). For high rainfall stress, the likelihood was only statistically significant for both years. This high rainfall scenario reduced households' likelihood of owning additional livestock species by 8%.

Table 10. OLR – likelihood of additional livestock species under climate stress

VARIABLES	ODDS RATIO	SE	P>Z
Controls = yes			
Heat stress			
2nd year before survey	0.941	0.020	0.005**
1st year before survey	1.037	0.018	0.038*
both years	1.275	0.038	0.000***
Low rainfall stress			
2nd year before survey	1.118	0.022	0.000***
1st year before survey	1.152	0.034	0.000***
both years	1.303	0.037	0.000***
High rainfall stress			
2nd year before survey	0.960	0.021	0.063
1st year before survey	1.016	0.022	0.466
both years	0.923	0.028	0.009**

n = 132,289
Wald chi2 = 32932.64
P>chi2 = 0.000
Pseudo R2 = 0.160

Multinomial logistic regression model

The final model in this study addressed herd composition in response to climate stress. Using a multinomial logit model (MLR), I considered whether a household owned no livestock, only chickens, goats but not cattle (regardless of chicken ownership), and whether a household owned cattle (table 11). This arrangement kept outcome variables to a minimum while maintaining relevance, as each category, respectively, represents an increasing level of investment in livestock by the household.

The model found that, relative to owning no livestock, the likelihood of only chicken ownership increased roughly 18% if there was heat stress in Y1 and 75% if there was heat stress present both years. The scenario in which households owned goats but not cattle also showed a dramatic increase during these time periods. Heat stress in Y1 increased the likelihood of goat ownership by 28% and if heat stress was present in both years, the likelihood of goat ownership increased by 63%. As in the binary logit model, the likelihood of goat ownership decreased (22%) if there was heat stress present in Y2 but not Y1. The likelihood of cattle ownership was again less sensitive to heat stress, increasing by 7% if stress was present in Y1 and 13% if stress was present both years.

Low rainfall stress increased the likelihood of only chicken ownership compared to owning no livestock modestly: 7%, 10%, and 10% for Y2, Y1, and both years, respectively. Low rainfall stress increased the likelihood of goat ownership compared to owning no livestock more impressively by 18%, 25%, and 51% in Y2, Y1, and both years, respectively. Interestingly, the likelihood of cattle ownership as compared to the reference category was more sensitive than only chicken ownership under the low rainfall stress conditions. The likelihood of cattle ownership increased by 8% for Y2, 25% for Y1, and 27% for both years if low rainfall stress was present.

Herd compositions were much less sensitive to the impact of high rainfall stress. The only statistically significant finding under conditions of high rainfall stress was that, compared to owning no livestock, chicken ownership was 17% more likely if there was high rainfall stress in both years prior to the survey.

Table 11. MLR – herd composition under climate stress (no livestock reference)

VARIABLES	ODDS RATIO	SE	P>Z
Controls = yes			
No livestock (reference)			
Owns chickens only			
Heat stress			
2nd year before survey	0.966	0.034	0.326
1st year before survey	1.175	0.033	0.000***
both years	1.754	0.087	0.000***
Low rainfall stress			
2nd year before survey	1.067	0.030	0.022*
1st year before survey	1.103	0.050	0.031*
both years	1.098	0.051	0.044*
High rainfall stress			
2nd year before survey	1.046	0.035	0.175
1st year before survey	0.963	0.032	0.253
both years	1.171	0.055	0.001**
Owns goats but not cattle			
Heat stress			
2nd year before survey	0.784	0.041	0.000***
1st year before survey	1.278	0.041	0.000***
both years	1.633	0.093	0.000***
Low rainfall stress			
2nd year before survey	1.180	0.042	0.000***
1st year before survey	1.251	0.070	0.000***
both years	1.509	0.082	0.000***
High rainfall stress			
2nd year before survey	1.043	0.043	0.310
1st year before survey	0.975	0.038	0.520
both years	1.017	0.061	0.781
Owns cattle			
Heat stress			
2nd year before survey	1.015	0.035	0.673
1st year before survey	1.066	0.029	0.017*
both years	1.133	0.052	0.006**
Low rainfall stress			
2nd year before survey	1.083	0.036	0.017*
1st year before survey	1.247	0.059	0.000***
both years	1.268	0.059	0.000***
High rainfall stress			
2nd year before survey	0.961	0.034	0.260
1st year before survey	1.020	0.036	0.570
both years	0.980	0.048	0.675

n = 132,289
P>chi2 = 0.000
Wald chi2 = 35983.40
Pseudo R2 = 0.235

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Table 12. MLR – herd composition under climate stress (owns cattle reference)

VARIABLES	ODDS RATIO	SE	P>Z
Controls = yes			
Owns cattle (reference)			
Owns no livestock			
Heat stress			
2nd year before survey	0.985	0.034	0.673
1st year before survey	0.938	0.025	0.017*
both years	0.883	0.040	0.006**
Low rainfall stress			
2nd year before survey	0.923	0.031	0.017*
1st year before survey	0.802	0.038	0.000***
both years	0.789	0.037	0.000***
High rainfall stress			
2nd year before survey	1.040	0.036	0.260
1st year before survey	0.980	0.035	0.570
both years	1.021	0.050	0.675
Owns chickens only			
Heat stress			
2nd year before survey	0.952	0.036	0.196
1st year before survey	1.102	0.032	0.001***
both years	1.548	0.076	0.000***
Low rainfall stress			
2nd year before survey	0.986	0.034	0.674
1st year before survey	0.884	0.044	0.014*
both years	0.866	0.045	0.006**
High rainfall stress			
2nd year before survey	1.088	0.039	0.019
1st year before survey	0.944	0.035	0.120
both years	1.195	0.062	0.001***
Owns goats but not cattle			
Heat stress			
2nd year before survey	0.773	0.042	0.000***
1st year before survey	1.199	0.039	0.000***
both years	1.441	0.081	0.000***
Low rainfall stress			
2nd year before survey	1.090	0.043	0.030*
1st year before survey	1.003	0.058	0.953
both years	1.191	0.071	0.004**
High rainfall stress			
2nd year before survey	1.085	0.046	0.056
1st year before survey	0.956	0.040	0.276
both years	1.038	0.065	0.549

n = 132,289
P>chi2 = 0.000
Wald chi2 = 35983.40
Pseudo R2 = 0.235

Lastly, it is also instructive to look at this model with cattle ownership as the reference category to demonstrate how different herd compositions and levels of livestock investment compare to one another (table 12). When looked at this way, owning only chickens is likelier under conditions of heat stress (10% in Y1 and 55% for both years) than owning cattle. Likewise, owning goats but not cattle is likelier under conditions of heat stress in Y1 and both years (20% and 40%, respectively), though there is again the unexpected result that under conditions of heat stress in Y2, goat ownership becomes less likely (by 23%), in this case, as compared to cattle.

For conditions of low rainfall stress, owning only chickens is more likely than owning cattle for Y1 (12%) and both years (13%). Goat ownership becomes slightly more likely than cattle ownership under low rainfall stress in Y2 (9%) and is additionally more likely if the stress was present both years (19%). Under conditions of high rainfall stress, only chicken ownership became more likely than cattle ownership and only if the stress was present in both years (20%).

Discussion

General findings

Overall, the results of these analyses suggest that livestock ownership and diversification of livestock portfolios are indeed smallholder responses to climate stress in SSA, providing evidence in favor of hypotheses 1, 2, and 3 outlined in the background section (above). In these models, chicken ownership is the most sensitive dependent variable to heat and low rainfall stress, followed by goat ownership, while cattle ownership is the least responsive variable to climate stress. It is probably not coincidental that these results reflect the level of investment required for each species. Chickens are the most financially accessible livestock in the models while cattle are the most expensive. Thus, chickens and goats are more easily acquired (or sold) as needed. This finding resonates with Anbacha & Kjosavik (2021) who found that poultry farming in Ethiopia was an opportunity for women and poor households and with Liao et al. (2016) who show, also in Ethiopia, that poor households switch to goats from cattle at higher rates than wealthier households. Crop farmers, therefore, could more easily diversify into chickens and goats than cattle when conditions are adverse for farming. Moreover, these animals' biological characteristics make them hardier in these harsh conditions than cattle, requiring, pound-for-pound, fewer calories and less water to remain healthy.

The results also indicate that goat ownership is less likely under conditions of rainfall stress in both Y1 & Y2. This result may reflect the fact that, under certain conditions, a one-standard deviation increase in rainfall for six or more months is felt more as a boon than a stress, perhaps in areas that tend to be more arid. If rainfall becomes more abundant, then presumably crop farming becomes easier. Cattle also become more attractive investments as grass (i.e., feed) grows quickly, and water is more accessible. Under harsher conditions of high precipitation, on the other hand, standing water threatens all ruminants with an additional disease burden. This risk may be more tolerable for large and expensive animals like cattle and less tolerable for smaller and more fungible animals like goats. Under conditions of flooding, which could adversely affect crop agriculture as well, goats are still not an attractive option as they are small enough to be killed in floodwaters. These findings indicate that hypothesis 4 needs to be amended to account for the result that cattle ownership is more attractive under conditions of high rainfall stress.

While the climate stress variables are the primary focus of this study, other factors associated with livestock ownership should not be overlooked. Female-headed households, for example, face barriers in obtaining livestock at the same level as male-headed households. Poorer households also have more difficulty acquiring livestock. If we are interested in livestock for their adaptive capacity to build resilience against climate change, then it should be concerning that the most vulnerable households also appear to have the most trouble obtaining livestock.

Divergence from previous studies

The findings in this study differ somewhat from those in Seo & Mendelsohn (2008) and Kabubo-Mariara (2008). Those studies found that cattle numbers were more sensitive to precipitation and temperature than goats and chickens. The models in this study, however, prior to inclusion of the climate stress variables, found that chickens and cattle ownership were less responsive to differences in temperature than goat ownership, and goat and cattle ownership were more sensitive to differences in rainfall than chicken ownership. It is hard to compare these findings directly with one another given that Seo & Mendelsohn (2008) and Kabubo-Mariara (2008) distinguished between beef and dairy cattle in their models while the data I used from the IPUMS DHS did not distinguish between these types of cattle. Had these cattle data been disaggregated, my models may have shown more sensitivity and different effects for each cattle type. The sensitivity of goat ownership to climate conditions, however, does seem to be a major point of departure between our studies.

One explanation for the discrepancy in sensitivity of goats to climate may be the difference in geographical distribution between Seo & Mendelsohn (2008) and Kabubo-Mariara (2008) and this study, as seen in figure **5-1**. Kabubo-Mariara's (2008) study took place in Kenya (East Africa), and Seo & Mendelsohn (2008) use data from North, East, West, Central, and Southern Africa and the Sahel. In contrast, this study has a concentration of data from Southern Africa plus Madagascar, Mali, Burkina Faso, and Cameroon. Seo & Mendelsohn (2008), moreover, consider overall livestock numbers owned by the household rather than a binary ownership variable, which could lead our two studies to consider different populations, with shifts in my study possibly representative of a more precarious population. More research will be required to gain clarity into these effects of geography and movement in numbers of livestock versus ownership of species.

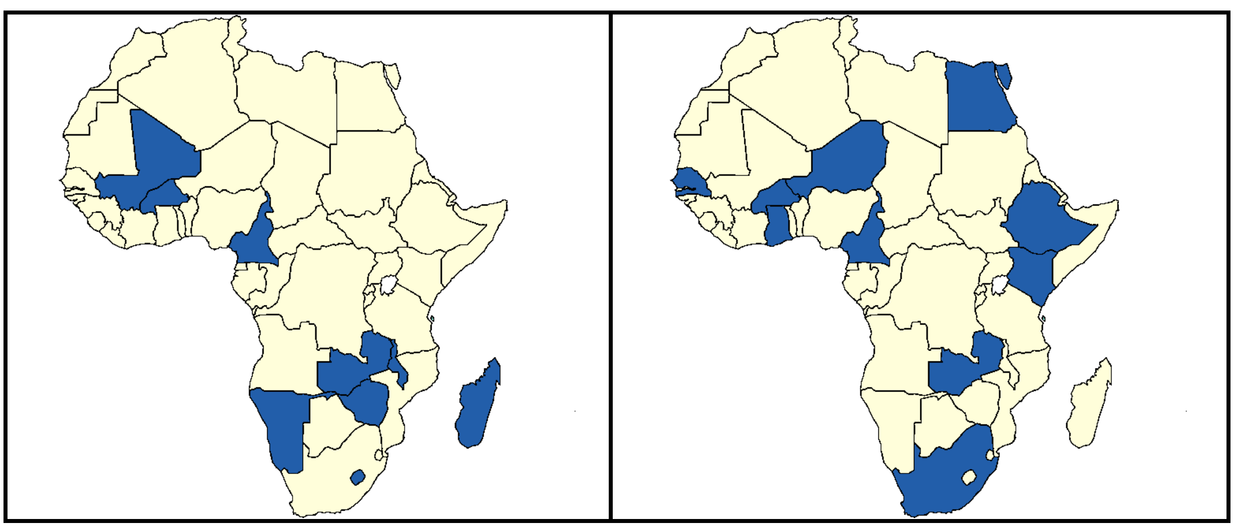

Figure 2: Left – geographical distribution of countries in this study; Right – distribution of countries in Seo & Mendelsohn (2008). Kabubo-Mariara (2008) used data from Kenya (East Africa)

Limitations

The most surprising result was the reduced likelihood of goat ownership if heat stress was present in Y2. Possibly, this result is an idiosyncratic finding that would not be reproduced by follow-up studies using a different set of surveys. One of the biggest limitations of this dataset is that it does not contain longitudinal household data. Therefore, some of the conditions considered in these models are contingent on what was occurring in particular countries and years which may not be representative of long-term conditions. Consider table 5-1 below which shows the presence of heat stress by country and year. As we saw in the background section above, for a variety of cultural, economic, ecological, and other reasons, goat ownership is not uniformly popular across SSA. So, when we rely on climate data from different countries across the continent, we run the risk of overrepresenting ungeneralizable data from our sample. From table 5-1, it is clear that Southern Africa, with the exception of Namibia, is underrepresented for heat stress in Y2. Namibia, moreover, has an arid climate and is much more reliant on livestock than its neighbors in the region that are represented in this study. Therefore, I hypothesize that the finding that the likelihood of goat ownership decreases if a household experienced heat stress in Y2 is spurious, and that, in fact, households that experienced heat stress in Y2 were places where goat ownership was less likely in the first place. This hypothesis needs additional testing with more studies like this one, or, ideally, large-scale, longitudinal household surveys alongside ethnographic inquiries about decision-making around herd composition.

Table 13: Households experiencing heat stress by country and year

Sample	Neither year	Y2	Y1	Both years	Total
Burkina Faso 2010	246	2607	4,383	4,297	11,533
Cameroon 2011	8,756	1,038	804	357	10,955
Lesotho 2009	7,826	0	0	0	7,826
Lesotho 2014	331	0	7,556	0	7,887
Madagascar 2008	9,245	4,779	0	0	14,024
Malawi 2004	5,590	2,003	4	1	7,598
Malawi 2010	1,287	0	13,838	677	15,802
Mali 2012	3,205	3,258	0	187	6,650
Namibia 2006	1,213	1,999	0	2,254	5,466
Namibia 2013	1,455	162	1,520	2,713	5,850
Zimbabwe 2005-6	250	0	6,004	66	6,320
Zimbabwe 2010-11	2,253	347	2,867	949	6,416
Zimbabwe 2015	6,361	0	2	0	6,363
Zambia 2007	5,171	196	751	0	6,118
Zambia 2013	13,481	0	0	0	13,481
Total	66,670	16,389	37,729	11,501	132,289

Another limitation of this study was the availability of livestock data. I chose to examine cattle, goat, and chicken data because these are widespread livestock species throughout SSA, and these species had the most complete data in the IPUMS DHS dataset. The data, however, do not distinguish between dairy and beef cattle which, as noted above, may affect the likelihood of cattle ownership. The data also do not include sheep, which might have provided a fuller understanding of the dynamics between climate and livestock.

As alluded to above, despite this study's large sample size, the geographical range represented is still somewhat lacking (figure 2). Compared to other regions, Southern Africa is overrepresented. Regions such as the Sahel and East Africa are almost completely unrepresented. So, while this study takes an important step toward generalizing climate-livestock relationships in SSA, there remains a need for studies with broader regional inclusion, or at least studies that focus specifically on East Africa and the Sahel. These regions have deep livestock-keeping traditions, including pastoralism, and there are thus strong cultural considerations for livestock ownership in East Africa and the Sahel beyond the generally rationalist economic approach undertaken in this study. We might expect, then, that certain livestock species are less sensitive to climate stressors in these regions of Africa than in others. Future studies including expanded regional and longitudinal data could strengthen the causal inferences made in this study.

Lastly, because these models rely on household data, they offer no additional insight into the intra-household dynamics of livestock ownership. We saw that female-headed households are less likely to own livestock, especially cattle, but we do not know how much (or which) livestock women own within male-headed households.

Conclusion

This study found that households in SSA are likely to diversify their livestock portfolios under conditions of heat and low-precipitation stress, particularly with chickens and goats. These findings largely comport with previous literature, reinforcing the broad accuracy and contribution of these more geographically delimited studies. However, this study does have drawbacks, including low geographical representation and the use of cross-sectional (as opposed to longitudinal) household survey data. The latter issue may have led to a spurious finding that heat stress in Y2 was associated with a decrease in the likelihood of goat ownership.

Despite these drawbacks, this study makes an important advance in identifying generalizable relationships between livestock and climate stress in SSA. If smallholders do choose livestock ownership and diversification in the face of climate stress, as seems to be the case, that finding gives governments, international organizations, and non-governmental organizations important information about the needs of these populations. For example, if a region is experiencing recurrent heat and low-rainfall stress, we can assume that many households in the region will want to diversify their livestock portfolios. Providing capital, extension education, and veterinary services can build on adaptive strategies households are already using to reduce vulnerability and increase climate change resilience. Such efforts should also consider factors such as gender and household wealth. The findings of this study suggest that chickens and goats are either easier or more desirable to obtain than cattle for these populations during times of climate stress but are still often out of reach for many households. Qualitative research can help us identify the barriers women and poor households face with respect to livestock ownership and whether, during times of climate stress, small livestock are more accessible, more desirable, or both. Policymakers and practitioners can then use that information to inform their work.

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Data Availability

The datasets analyzed during the current study were generated using data available on the IPUMS DHS website: https://www.idhsdata.org/idhs/ The dataset generated by the author is available upon request.

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