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Pastoralist decisions to participate in livestock marketing systems during drought seasons: evidence from kenyan arid and semi-arid regions

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Pastoralist households in Kenya's arid and semi-arid lands (ASALs) rely heavily on livestock trade for livelihoods and income. Between 2021 and 2023, the region experienced its worst drought in four decades, marked by six consecutive failed rainy seasons. This study investigates the factors influencing pastoralists' choice of livestock market channels during this period, focusing on the effects of drought, conflict, and livestock production systems. It also examines how different sources of livestock market information shape trading decisions. Data were collected from 1,053 households using a multistage sampling approach. Analytical methods included Multivariate Probit (MVP) regression and Classification and Regression Tree (CART) analysis. Findings reveal that informal networks, especially neighbours and family, were the most influential sources of market information. In contrast, formal channels such as mobile phone calls and radio had limited impact. Households affected by drought were more likely to sell steers through butcher outlets, reflecting urgent liquidity needs. Conflict significantly reduced participation in local markets, highlighting how insecurity limits access. Across all livestock types, namely steers, heifers, bulls, cows, sheep, and goats, pastoralists engaged in multi-channel marketing strategies shaped by herd size, household demographics, and external shocks. These results underscore the need to strengthen both traditional and digital market information systems that provide timely, localized livestock market intelligence. Supporting livestock marketing cooperatives and Common Interest Groups (CIGs) is also vital to improving coordination and bargaining power. Such interventions are essential for enhancing resilience, market participation, and economic inclusion in Kenya's drought-prone pastoralist areas.

KEYWORDS

pastoralist, livestock marketing channels, cattle rustling, drought, sub-saharan

Introduction

Approximately half of the Earth's land surface is classified as dry or semi-arid, making it largely unsuitable for crop cultivation but critical for sustaining livestock-based livelihoods. Globally, these rangelands support the food security and incomes of over 2.5 billion people. In East Africa, more than 30 million pastoralist households rely on livestock trade as their primary means of livelihood and income (Homewood, Rowcliffe, De Leeuw, Said, & Keane, 2019). Kenya represents a significant case within this regional context. The country hosts approximately nine million pastoralists who inhabit about 70% of the arid and semi-arid lands (Sulle, 2021). These pastoralists manage livestock assets valued at over USD 1 billion, contributing an estimated 42% to the national agricultural GDP and 12% to the total GDP (Fava et al., 2021; Nyariki and Amwata, 2019). Pastoralist households, primarily dependent on livestock for their sustenance (Mburu et al., 2017), play a crucial role not only in primary production but also in the broader economy. The pastoral sector generates employment along various nodes of the value chain, including livestock trade, transportation services, slaughterhouses, leather industries, butcheries, and restaurants (Nyariki and Amwata, 2019).

Global meat consumption *per capita* is projected to increase by 0.3% annually, reaching 35.4 kg (retail weight equivalent) by 2030. During the same period, global consumption of meat proteins is expected to rise by 14% relative to the 2018–2020 baseline, driven primarily by population and income growth (FAO, 2021). Sub-Saharan Africa (SSA) is anticipated to experience the highest growth rate in meat demand, estimated at 15%, largely due to rapid population expansion. However, growth in major meat-producing and exporting regions is expected to remain modest. Despite the sector's growing importance and potential, livestock marketing systems in SSA remain largely informal and fragmented, resulting in low productivity, weak market integration, and limited public and private investment (Nyariki and Amwata, 2019; Schaffnit-Chatterjee et al., 2014). Recent studies characterize livestock markets across the region as volatile and facing structural barriers to growth (Aklilu, 2008; Descheemaeker et al., 2016).

The long-term viability of pastoralist livelihoods, particularly in arid and semi-arid environments, is increasingly threatened by the growing impacts of climate change. Pastoralist communities across SSA are facing heightened exposure to climate extremes, including prolonged droughts, erratic rainfall, flooding, and land degradation (Ndiritu, 2021). According to Assan (2022) and Inmanet al. (2020), pastoralists are living increasingly precarious lives, with compounding stressors such as disease outbreaks, resource conflicts, and overgrazing intensifying livestock production uncertainty. Drought-induced stress is shaped by multiple dimensions such as severity, duration, timing, and spatial extent, all of which influence local resilience outcomes conditions (Wilhite et al., 2014).

Recently, the arid and semi-arid lands (ASALs) of Kenya, Ethiopia, and Somalia experienced the worst drought in four decades, following six consecutive failed rainy seasons (between 2021 and 2023) (ReliefWeb, 2024). The drought decimated livestock populations, disrupted crop production, and left nearly 2.4 million pastoralists in urgent need of humanitarian assistance (NDMA, 2023). Water sources dried up, compelling families to travel long distances in search of water and pasture, often triggering inter-community tensions and escalating conflict.

The depletion of vegetation and the collapse of grazing systems led to widespread livestock mortality and the erosion of livelihoods. Building resilience in ASAL regions demands targeted support for adaptive strategies, including flexible mobility patterns, indigenous knowledge systems, and diversified market participation. While enhancing livestock productivity is often cited as a resilience pathway, this must be rooted in locally defined priorities and the socio-ecological realities of pastoral production systems (Ndiritu, 2020).

Nonetheless, the livestock sector continues to face persistent marketing challenges. These include inadequate infrastructure, poor coordination across the value chain, limited access to reliable market information, weak market organization, and low consumer purchasing power (McDermott et al., 2010). In particular, the lack of investment in critical infrastructure and information systems along the supply chain has constrained efficient market responses and contributed to recurring inefficiencies (Roba et al., 2018). Strengthening coordination across the livestock supply chain is essential for aligning market actors and ensuring responsiveness to demand fluctuations (Kyeyamwa et al., 2008).

While there have been increasing calls for improvements in livestock marketing systems (Baker and Enahoro, 2023) and greater collaboration along the livestock value chain (Herrero et al., 2013; Roba et al., 2018), the sector remains largely unregulated and informally structured across much of SSA. The absence of a coherent livestock marketing policy has resulted in low levels of investment in marketing infrastructure and coordination, particularly in East Africa (Adicha et al., 2021; Tiki and Little, 2022). This institutional gap has contributed to persistent inefficiencies in pastoral livestock markets (Anno and Elenica, 2021).

In Kenya's ASAL regions, livestock sales have become an increasingly critical coping strategy for pastoralist households. However, these markets remain highly volatile, especially during periods of environmental stress such as prolonged droughts. Pastoralists are often compelled to seek alternative market outlets that promise higher returns, typically within localized or regional networks (Ombasa and Kiruthu, 2020). Despite a growing body of literature on livestock marketing and supply chain coordination in SSA, particularly in East Africa, significant

knowledge gaps remain. Specifically, limited research has examined how intersecting factors such as drought, livestock-related conflict, and the structural features of production systems influence pastoralists' decisions to engage with specific marketing channels. Furthermore, there is insufficient understanding of how various sources of market information shape pastoralists' preferences for livestock outlets, particularly during climate-induced crises when timely market decisions are most critical. This study addresses critical knowledge gaps by investigating the dynamics of livestock marketing decisions among pastoralist households in Kenya's ASALs, particularly during periods of drought-induced stress. Specifically, it seeks to understand how environmental shocks and information systems shape market behaviour in pastoral economies.

The first objective is to examine how drought conditions, livestock-related conflict, and the structural characteristics of livestock production systems influence pastoralists' decisions to engage with specific livestock market outlet channels. These factors are pivotal in determining the timing, mode, and destination of livestock sales during climatic crises. The second objective is to evaluate the role of both formal and informal sources of market information in shaping pastoralists' market preferences during drought. By analysing the accessibility and perceived utility of different information channels, the study aims to assess how timely, accurate market information enables pastoralists to make more informed and strategic trading decisions under volatile conditions.

This research contributes to the literature in two substantive ways: First, it offers a micro-level analysis of the structural factors influencing livestock marketing information systems, with a focus on the flow and relevance of information across diverse market channels. By identifying key determinants of optimal channel selection, the study provides insights into how pastoralists can minimize livestock losses during prolonged droughts, enhance market access, and secure more favourable prices. These outcomes are essential for strengthening household incomes and advancing food security in ASAL regions; Second, the study applies Classification and Regression Tree (CART) to predict and interpret the influence of various information sources on livestock marketing channel choices. CART is a non-parametric machine learning algorithm that recursively partitions the data based on values of input variables to construct an interpretable tree structure. Each split in the tree corresponds to a decision rule that classifies the likelihood of a household using a specific livestock market channel based on access to different sources of marketing information.

Understanding how pastoralists interact with market information systems is crucial for the design of targeted interventions aimed at improving marketing efficiency, lowering transaction costs, and fostering the integration of pastoralists into more formal and resilient economic networks. Given the high levels of uncertainty and risk that characterize livestock trading in drought-prone environments, reliable and accessible market information is vital for negotiation, income generation, and long-term livelihood resilience.

The remainder of this article is structured as follows: Section *An overview of Kenya's livestock production market system* provides an overview of Kenya's livestock production systems, market structures, and marketing channels; Section *Materials and methods* outlines the materials and methods employed in the study; *Data and descriptive statistics* Section presents the data and summary statistics of the variables used in the empirical analysis, while *Decision tree models of livestock marketing channel choices* Section explores the sources of livestock marketing information and pastoralists' choices of market channels and Section *Estimating the factors that influence market channel choice* reports the empirical results on the factors influencing livestock market channel selection; Section *Summary and conclusion* offers the study's key conclusions and policy implications.

An overview of Kenya's livestock production market system

Uncertainty in food supply is primarily driven by inconsistencies in production and distribution, which are shaped not only by socio-political and economic instability but also by increasing climate variability (Luo et al., 2021). In an evolving and competitive global livestock market, policy stakeholders have recognized the need for reliable and efficient supply chain operations. Consequently, effective livestock supply chain management has emerged as a cornerstone of sectoral sustainability and competitiveness (Eeswaran et al., 2022). Supporting this position, Dizyee et al. (2017) emphasize the importance of coordinated supply chains for enhancing producer returns and promoting sectoral growth, as demonstrated in Botswana's beef industry.

For the livestock sector in Sub-Saharan Africa (SSA) to realize its full potential, scholars such as Kebebe (2019) and Lutta et al. (2021) advocate for more collaborative, synergistic relationships among actors across the supply chain. These relationships must adapt to an increasingly globalized marketplace, characterized by rapid product diversification and technological innovation. Jayne e al. (2021) and AU (2013) further underscore that livestock supply chains in SSA are inherently complex, involving diverse stakeholders whose effective coordination is essential for equitable development. Addressing the needs of pastoralist communities, in particular, demands intentional inclusion within these systems and deliberate efforts to build shared value. Accordingly, supply chain actors and policymakers must work toward creating inclusive systems that strengthen performance, adaptability, and resilience.

In Kenya, livestock production is driven by both pastoralist systems and large-scale commercial ranching. Pastoralism

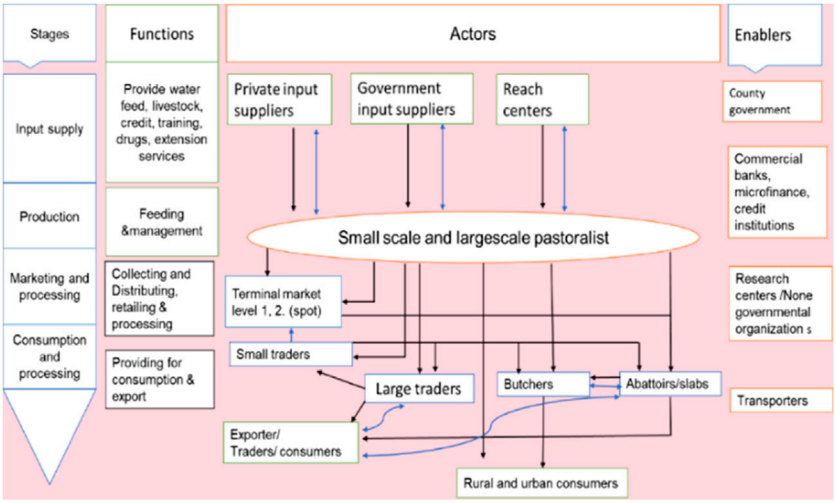

FIGURE 1
Flow chart of the meat value chain in Kenya adapted from Anno (2024).

accounts for over 60% of meat production in the country, generating approximately 154,968 metric tons annually from various animal species (Nyariki and Amwata, 2019). While pastoralism is generally characterized as a low-input, low-output production system based on mobility and communal resource governance, commercial ranches are more market-oriented, employing intensive inputs and formal breeding programs to maximize output. These ranches are also important for producing pedigree steers and fattening cattle for premium markets.

Despite their central role in national meat production, pastoralists face mounting challenges due to shifting market demands, rendering livestock production increasingly risky (Mburu et al., 2017). Their long-term viability is threatened by a complex mix of ecological, institutional, and socio-political factors. Climate change, notably through recurrent and prolonged droughts, exacerbates livestock mortality and pasture scarcity, but it is far from the only challenge. Policy-related constraints, such as limited formal recognition of pastoral mobility, exclusion from national development frameworks, and inconsistencies in land-use policy enforcement, further undermine pastoralists' resilience (de Vries, 2019).

Access to critical resources such as water and pasture is increasingly constrained by land fragmentation, sedentarization pressures, and the encroachment of agriculture, conservation initiatives, and commercial investments into traditional grazing areas (AU, 2013). Simultaneously, the weakening of traditional governance systems, coupled with fragile formal institutions, has diminished local capacity to manage communal resources and resolve conflicts related to grazing routes and seasonal migrations (Behnke et al., 2011). These governance failures are compounded by chronic underinvestment in pastoralist regions, including poor infrastructure, inadequate public service delivery, and limited access to formal markets. As Descheemaeker et al. (2016) argue, while climate variability remains a critical threat, its impact is significantly amplified by systemic institutional and policy failures that limit pastoralists' capacity to adapt, compete, and thrive within formal economic systems.

Figure 1 illustrates the structure of Kenya's livestock supply chain, highlighting key actors and stages from production to market access. In pastoralist areas, informal local markets serve as key trading hubs, typically held weekly and characterized by direct price negotiations between buyers and sellers (Bassa and Woldeamanuel, 2019). While middlemen provide logistical convenience, they often reduce producers' margins through exploitative pricing strategies. Additionally, itinerant traders and butchers travel directly to pastoralist settlements to purchase livestock for resale or slaughter, offering ease of transaction but often at prices below those offered in more competitive markets (Guyo et al., 2024). Some pastoralists sell directly to slaughterhouses that serve urban centres. Although these formal markets provide consistent demand, they also impose stricter quality and weight standards that many producers struggle to meet. In this study, livestock marketing channels are conceptualized as follows:

- Trader channels: Mobile intermediaries who purchase livestock directly from households and transport them to regional or urban markets for resale.
- Local market: Informal, weekly trading venues with limited external trader participation, typically located within pastoralist communities.

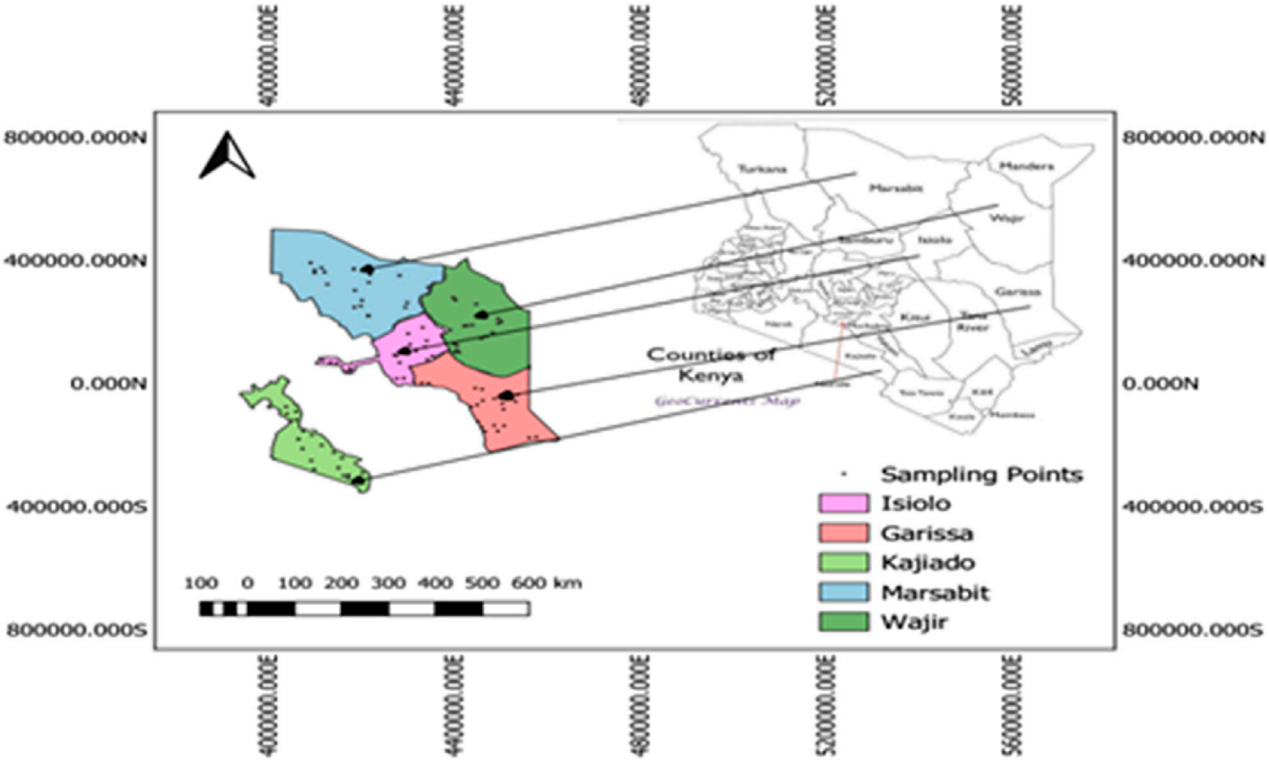

FIGURE 2
Study area.

- Local butcher markets: Local meat vendors who buy animals for immediate slaughter and sale in nearby communities.
- Slaughterhouse markets: Formal slaughter facilities serving urban markets, often requiring adherence to regulated quality standards.
- Terminal markets: Large, centralized markets, often urban, serving broader regional or cross-border demand.

This classification provides a framework for analysing how pastoralists navigate different marketing options, particularly under stress conditions such as drought, when timely and profitable market access becomes a critical determinant of household resilience.

Materials and methods

Sampling procedure and data

This study targeted pastoralist communities in five counties in Kenya, namely Kajiado, Garissa, Isiolo, Marsabit, and Wajir, which were purposively selected to reflect the diversity of pastoralist systems across the regional zones: Marsabit (northern), Wajir (northeastern), Garissa (southeastern), Isiolo (central), and Kajiado (southern) (see Figure 2). These counties were also chosen based on logistical accessibility and security considerations critical for fieldwork implementation. A multi-stage sampling approach combining both probabilistic and non-probabilistic techniques was used to ensure a representative and robust sample of pastoralist households. A validated sampling frame from the Ministry of Livestock Development provided a baseline of households across the target counties. Within each county, specific sub-counties (see Supplementary Appendix SA2 map) were identified in collaboration with county extension officers to ensure spatial and production system diversity. Wards and villages were then randomly selected based on factors such as population density and proximity to livestock routes and markets. At the village level, systematic random sampling was employed using available livestock registers lists. In cases where no such lists were available, a random walk procedure was applied starting from a central village location. While probabilistic methods were prioritized to ensure representativeness, non-probabilistic approaches were cautiously employed in areas with limited accessibility due to security or logistical challenges. The final sample comprised 1,053 pastoralist households, calculated using standard statistical formulas to achieve a 95% confidence level and a

TABLE 1 Distribution of sampled households by constituency and county.

County	Sample distribution	Sub counties	Number of pastoralists households
Wajir	210	Griftu	35
		Eldas	35
		Khorof Harar	35
		Wajir west	35
		Wajir east	35
		Wajiir south	35
Garissa	211	IJARA	42
		Balambala	42
		Daadab	42
		Garissa township	43
		Ijara	42
Kajiado	210	Kajiado North	42
		Kajiado Central	42
		Kajiado East	42
		Kajiado West	42
		Kajiado South	42
Isiolo	210	Garba Tulla	42
		Isiolo south	42
		Merti	42
		Kinna	42
		Galbatulla	42
Marsabit	212	Marsabit Central	71
		Marsabit North	71
		North Horr	70
Total			**1053**

margin of error of ±3.02%, thereby ensuring statistical precision in assessing livestock ownership, market participation, and livelihood patterns in Kenya's arid and semi-arid lands.

The distribution of the study areas and selected sub-counties is presented in Table 1.

A quantitative household survey was administered to respondents aged 18 years and above. The data collection was conducted using structured questionnaires programmed on Android tablets via the KOBO Toolbox platform. A total of 34 trained enumerators carried out the data collection between January and March 2023, a period corresponding to the dry season in many ASAL counties when livestock-related challenges and market activity tend to intensify. Fieldwork was met with several logistical challenges. These included difficult terrain, poor road infrastructure limiting access to remote pastoralist settlements, and sporadic security concerns in areas experiencing livestock-related conflicts. Despite these constraints, data collection was successfully completed across all sampled regions.

Empirical methods

Classification and regression tree (CART) model

Pastoralist households operate within fluid, high-risk environments where their livestock marketing strategies are shaped by a combination of seasonal needs, drought conditions, distance to market centres, and socio-economic constraints. Rather than relying on a single market outlet, pastoralists often sell their animals through multiple

marketing channels simultaneously. These channels include traders, local markets, local butchers, slaughterhouses, and terminal markets, each serving a distinct function within the broader livestock value chain.

A critical factor influencing the choice of these market channels is the source of marketing information that pastoralists rely on. These include mobile phone calls, traders, radio broadcasts, neighbours and family members, and social groups. Importantly, these information sources are not mutually exclusive; pastoralists often consult multiple sources in parallel. The complexity and interdependence of these sources introduce nonlinear dynamics into decision-making process patterns that traditional linear models may struggle to capture.

To address this challenge, the study applies a Classification and Regression Tree (CART) model to explore how different sources of livestock market information influence pastoralists' participation in various marketing channels. Unlike artificial neural networks (ANNs) that rely on black box learning algorithms, CART provides a transparent and interpretable framework for modelling nonlinear decision paths. CART is a non-parametric machine learning algorithm that recursively partitions the data based on values of input variables to construct an interpretable tree structure. Each split in the tree corresponds to a decision rule that classifies the likelihood of a household using a specific livestock market channel based on access to different sources of marketing information. The CART algorithm selected the most informative splits using the Gini impurity criterion and limited the maximum depth of each tree to three levels to improve interpretability and avoid overfitting.

Multivariate probit model

Pastoralist households often engage with multiple livestock marketing channels simultaneously, depending on their needs, livestock type, and prevailing market conditions. Recognizing this behaviour, the study employed a Multivariate Probit (MVP) model to examine the socioeconomic and contextual factors influencing pastoralists' participation across different marketing channels. The empirical choice framework involving the four identified marketing channels could theoretically be analysed using either multinomial or multivariate regression techniques. However, a key limitation of multinomial models is the Independence of Irrelevant Alternatives (IIA) assumption, which requires that the error terms across alternatives are uncorrelated (Greene and Hensher, 2003). This assumption is unsuitable for the current study, as pastoralists' decisions to sell through various marketing outlets are not mutually exclusive. In practice, many households simultaneously utilize multiple channels (e.g., traders, local markets, local butchers, slaughterhouses, and terminal markets), implying that the random error terms across these choices may be correlated.

To accommodate this interdependence, the study adopts a Multivariate Probit (MVP) regression model, which allows for joint estimation of binary choice equations while accounting for potential correlations across error terms. This approach captures the simultaneity in pastoralists' marketing decisions and the possibility that unobserved factors influencing one channel choice may also influence others. Following Ndiritu (2021), the MVP model is estimated using Maximum Likelihood Estimation (MLE). The model specification assumes that the latent utility derived from each marketing channel is influenced by a set of observed household and contextual characteristics, and the decision to use a particular channel is observed as a binary outcome Equation 1

$$A_i^* = \beta_{ij} X_j + \varepsilon_i \tag{1}$$

$$A_i = \begin{cases} 1 \, if \, A_i^* > 0 \\ 0 \, otherwise \end{cases}$$

where i = 1 . . . k denotes the choice of marketing channel used by pastoralists to sell livestock. The market choices are dummy variables that include Village market, trader market, abattoir market, butcher market, and main livestock market terminal. X_j is the control variables, β_{ij} is the vector of parameters to be estimated, while ε_i is the error term that is not necessarily correlated. Based on the sampling procedure, ε_i, error terms are distributed as multivariate normal with zero mean and variance–covariance matrix V, where V has values of 1 on the leading diagonal [$Q = \rho ij$].

Numerous studies that assess factors influencing the marketing channels have already employed multivariate probit estimation (Arinloye et al., 2015; Hao et al., 2018; Mutura et al., 2015). Jenkins et al. (2011) use this method to assess how different information sources, such as the private, extension, and media, influence how cotton producers adopt information while Mittal and Mehar (2016) estimate the socio-economic factors affecting the adoption of modern information and communication technology by farmers in India. They contend that when adoptions occur simultaneously, modelling adoption decisions using a multivariate probit framework enables increased estimation efficiency.

Results and discussion

Data and descriptive statistics

Table 2 presents the descriptive statistics for the surveyed pastoralist households across Kenya's ASAL regions. The data reveal that 80.7% of the households were male-headed, with the average age of the household head being 47.57 years. On average, household heads had completed approximately 4 years of formal education, while the highest level of education in a household was 9 years, indicating that children in these pastoral communities are more educated than their parents. The mean household size was 6.9 members, while the average monthly income stood at

TABLE 2 Variable definition and summary statistics.

Variable	Mean	Std. dev.
Age of the household head (HHH) (years)	47.58	14.07
Household size	6.903	2.873
Highest education level in the household (years)	9.120	5.044
Education years of the household head	4.258	5.169
Gender of the household head (1 = Male, 0 = Female)	0.807	
Household income (monthly in Ksh) in 2022/2023 years	13,274.5	20,336.4
Distance to the main market (KM)	30.402	46.3
Access to extension services in 2022/2023 years (1 = Yes, 0 = No)	0.026	
Received livestock marketing information in 2022/2023 years (1 = Yes, 0 = No)	0.332	
Livestock marketing contract in 2022/2023 years (1 = Yes, 0 = No)	0.057	
Membership to common interest group/association (1 = Yes, 0 = No)	0.031	
Livestock production affected by conflict in 2022/2023 years (1 = Yes, 0 = No)	0.398	
Livestock production affected by disease outbreak in 2022/2023 years (1 = Yes, 0 = No)	0.556	
Livestock affected by drought in 2022/2023 years (1 = Yes, 0 = No)	0.951	
Migration of livestock in search of pasture and water in 2022/2023 years (1 = Yes, 0 = No)	0.527	
Access to credit in 2022/2023 years (1 = Yes, 0 = No)	0.080	
Tropical Livestock Unit (TLU) owned before drought	48.52	80.07
Tropical Livestock Unit (TLU) of animals that died	18.58	28.08
Tropical Livestock Unit (TLU) owned after drought	24.74	52.56

KES 13,274.50 (approximately USD 94.89), which is considerably lower than the national average income of KES 20,123 (USD 143.84).

Only 3.1% of respondents reported being members of common interest groups, such as livestock marketing associations, indicating limited collective organization among pastoralist households. Moreover, 33% of households received livestock marketing information primarily through informal sources, particularly from relatives and neighbours. Formal marketing arrangements were rare; only 5.7% of respondents reported having formal contracts for livestock sales.

Pastoralists travelled an average of 31 km to access the nearest livestock market, highlighting potential barriers to market participation due to distance. The impact of drought was widespread, with 95.1% of households reporting drought-related disruptions. Additionally, 39.8% of households had experienced conflict-related incidents, primarily in the form of cattle raiding, which further disrupted livestock production and market access. The average livestock holdings prior to the drought stood at 48.52 Tropical Livestock Units (TLU), but this figure declined significantly to 24.74 TLU post-drought, illustrating the substantial impact of prolonged climatic stress on pastoralist asset bases.

Livestock marketing channels

Figure 3 presents the mean number of livestock sold by market channel, disaggregated by livestock type, namely heifers, steers, bulls, cows, sheep, and goats, across five primary outlets: traders, local markets, local butchers, slaughterhouses, and terminal markets. This analysis provides key insights into marketing behaviour among pastoralist households in Kenya's ASALs. Generally, the data reveals that sheep and goats are sold in the highest quantities across all market channels. Specifically, the mean number of sheep sold to all marketing channels was 13.48, while 11.033 goats were sold. Notably, the mean number of sheep sold to traders was 14.4, while 13.69 were sheep were sold in local markets and 13.54 in terminal markets. Slaughterhouses and local butchers served as mid-level channels primarily for the sale of bulls, cows, and goats, averaging between 3.4 and 4.5 animals per transaction. These outlets often absorb livestock unsuitable for long-distance transport or those sold under distress conditions such as droughts, diseases, or urgent financial needs (Kirui et al., 2022).

Heifers and steers were the least sold livestock types across all marketing channels. Mean number of heifers sold was between 2.3 (traders) and 3.75 (local markets), while steers ranged from 2.66 to 3.66 across channels. This lower turnover likely reflects

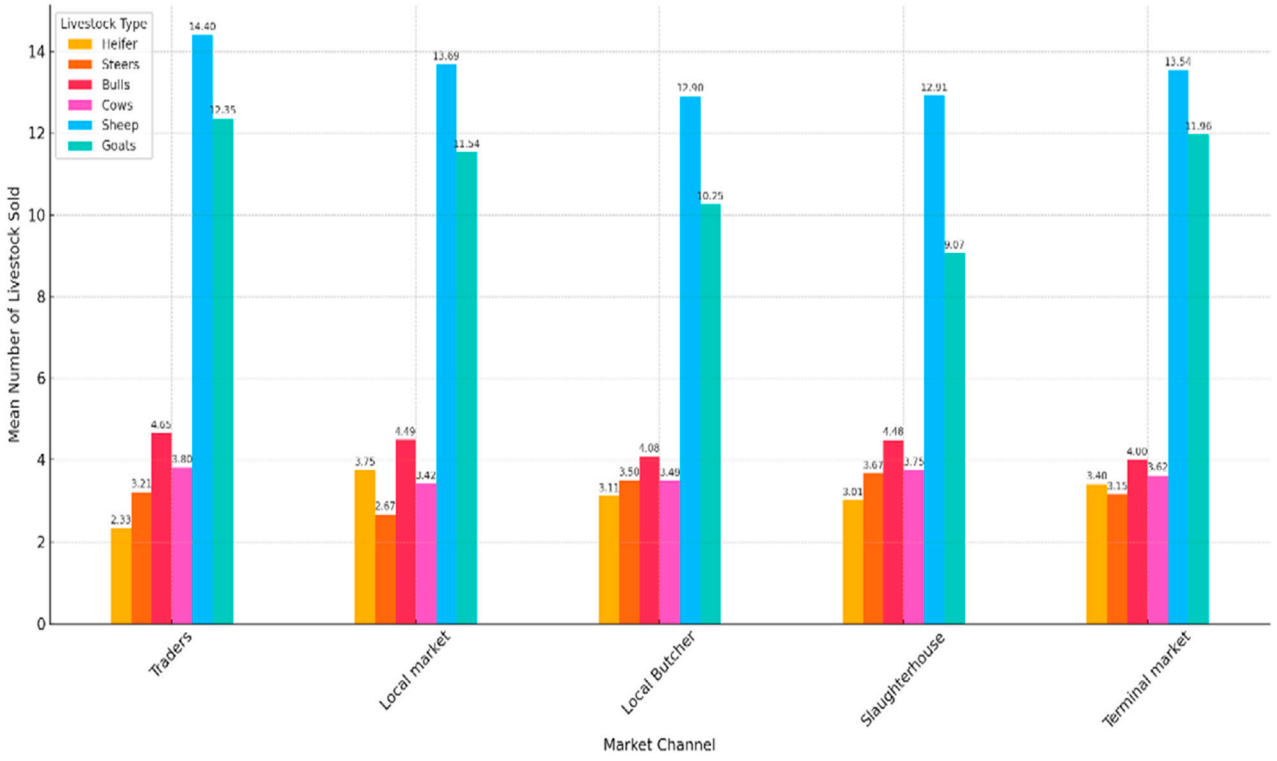

FIGURE 3
Mean number of livestock sold by market Channel.

their retention value within herds, with heifers used for breeding or future sales during favourable market conditions. Their limited sale aligns with herd management strategies aimed at sustainability and regeneration (Nyariki and Amwata, 2019, Osman, 2024).

Terminal markets recorded high numbers of livestock sales for both large and small livestock, with heifer, bull, and cow sales averaging 3.4, 4.0, and 3.62, respectively. These figures indicate that pastoralists strategically engage with terminal markets, likely when selling higher-value or better-conditioned animals. However, overall sales to terminal markets remain moderate, suggesting persistent barriers such as poor infrastructure, transport costs, and limited market information, consistent with findings by Muleta et al. (2019) and van der Lee et al. (2020).

The findings underscore the reliance of pastoralists on informal and trader-based channels, likely due to limited access to structured markets and infrastructure. According to Lutta et al. (2021), decisions regarding which animals to sell, where and when to sell them, and at what price remain complex, contributing to increased transaction costs especially for pastoralists who must travel long distances to access markets. Similarly, Wafula and Wasonga (2021) noted that pastoralist communities primarily sell cattle, goats, and sheep to local traders who act as intermediaries linking them to broader market networks.

The data reveals that of the 8.1% of households that sold one or more heifers during the study period, 60% sold heifers through village markets, while 86% relied on traders as intermediaries. In contrast, only 2% utilized abattoirs/slaughterhouses/slabs, and 22% sold heifers through butchers. Of the 10.9% of households that sold one or more bulls during the study period, the majority preferred selling through traders (81%), followed by village markets (55%) and butchers (15%). A smaller proportion (11%) chose abattoirs/slaughterhouses/slabs as their marketing outlet for bulls. Similarly, of the 63% of households marketing one or more small stocks such as goats and sheep, during the study period 87% sold goats to traders and 80% sold sheep to traders, using them as their primary market channel. Only 12% of the respondents who sold goats and sheep sold them to abattoirs/slaughterhouses/slabs combined with butchers, indicating a low uptake of formal processing and retail outlets. *Note that in all cases for a given animal type these percentages add up to more than 100% as households frequently sold multiple animals and used different market outlets for these sales during the study period.*

Figure 4 presents mean price data across various livestock marketing channels, revealing consistent patterns that initially suggest a price-based market hierarchy. Terminal markets consistently offer the highest average prices for most livestock

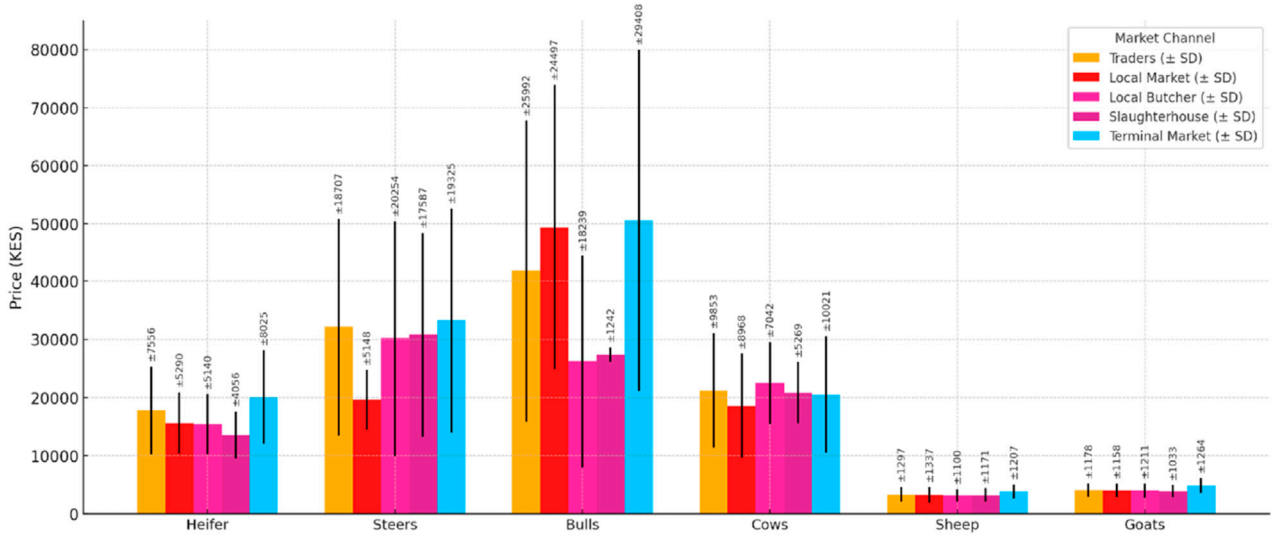

FIGURE 4
Livestock sales to marketing channels in Kenya Shillings (KES).

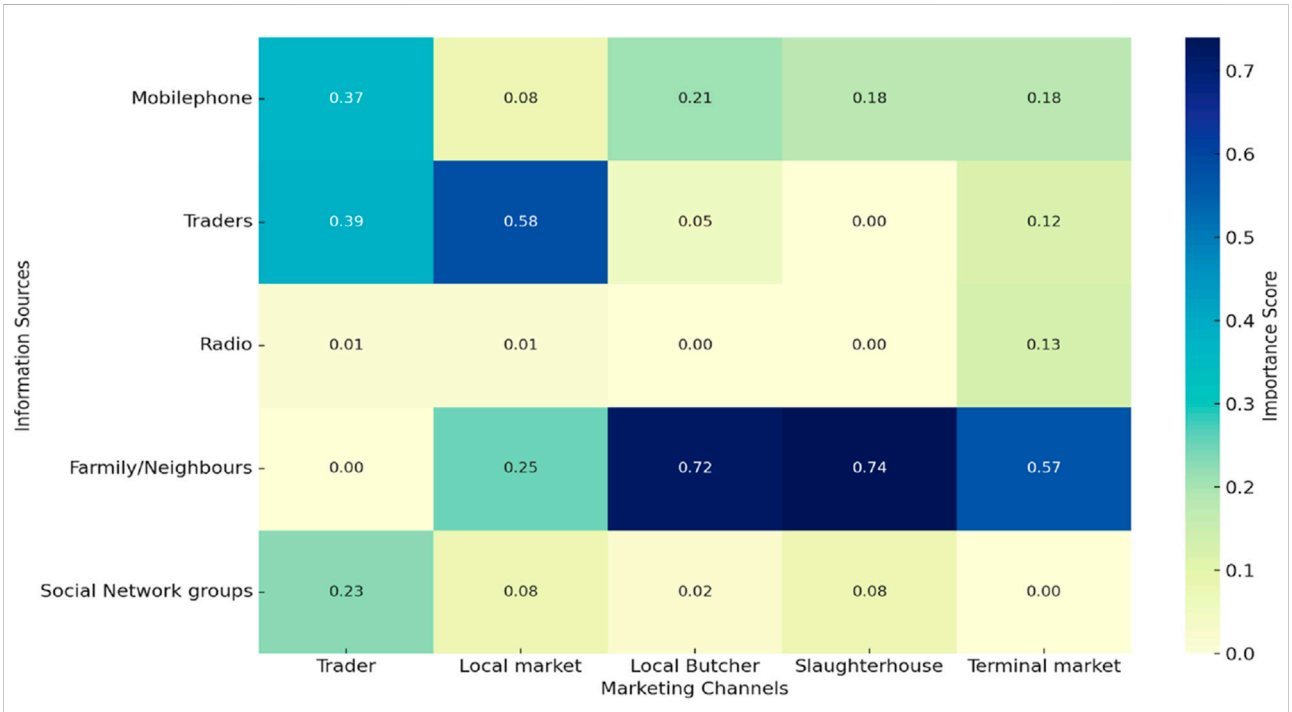

FIGURE 5
Heat map on livestock information sources vs. Marketing channels.

categories. Specifically, terminal markets recorded the highest mean prices for heifers (KES 20,070.10), steers (KES 33,315.79), bulls (KES 50,566.67), sheep (KES 3,840.56), and goats (KES 4,868.50). In contrast, the lowest mean prices were observed at slaughterhouses and local markets, such as bulls at slaughterhouses (KES 27,378.79) and steers at local markets (KES 19,564.10). An exception is noted for cows, where local butcheries offered the highest mean price (KES 22,483.80),

potentially indicating a preference for direct sales or niche consumer demand.

Although these price patterns suggest that terminal markets may provide greater financial returns, the decision-making process for pastoralist producers is far more nuanced. From the pastoralist's perspective, marketing choices are shaped less by nominal price differentials and more by the cumulative cost, logistical feasibility, liquidity constraints, and transaction reliability associated with accessing each market channel. These findings align with earlier research demonstrating that smallholder market participation is often constrained not by lack of price incentives but by fixed and variable transaction costs, time sensitivity of financial needs, and incomplete market access (Barrett, 2008).

The decisions to sell at terminal markets are not solely motivated by price considerations. Pastoralists noted that these markets offer bundled utility: they can sell livestock and simultaneously access goods and services unavailable or more expensive in local markets. Terminal markets also host financial services, including banks and mobile money agents, which are critical for transactions such as paying school fees or sending remittances. This supports findings from Fafchamps, Hill, and Change (2008), who emphasized that market participation is often tied to the availability of complementary services and infrastructure rather than price signals alone (McPeak and Barrett, 2001; Opiyo et al., 2015).

Decision tree models of livestock marketing channel choices

Figure 5 displays a heatmap visualisation of the normalised relevance scores obtained from decision tree models, illustrating pastoralist households' engagement in livestock marketing channels, including trader, local market, local butcher, abattoir, and terminal market. The heatmap illustrates how each information source contributed to the model's classification power, offering insights into which information channels most influence pastoralist decision to participate in marketing channels during drought periods.

The most consistently important information source across the models was family and neighbours, particularly for the use of local butchers (72%), slaughterhouses (74%), and terminal markets (57%). This underscores the persistent reliance of pastoralist communities on informal, trust-based networks for market decision-making. In these channels, especially slaughterhouses and butcheries, social referrals, local knowledge, and interpersonal relationships appear to outweigh more formal or technological sources. The trader's information source displayed high importance in predicting local market (58%) and trader (39%) participation. The finding suggests that market actors themselves act as critical intermediaries, particularly in semi-formal exchanges where buyers provide price, demand, and logistical information to sellers. Traders likely play a dual role both as market participants and as information conduits, guiding pastoralists' decisions on where and when to sell. Mobile phone calls ranked highest as the primary source of information for the trader channel (37%), followed by butchers (21%), terminal markets (18%), and slaughterhouses (18%). This data indicates that mobile phone calls are increasingly being used to access livestock market information, including prices and the best markets to sell at.

Previous findings show that pastoralists actively sought livestock market information through personal visits to markets, social interactions with friends, engagement with farmer groups, and mass media (Butt, 2015). Similarly, Roba et al. (2018) highlighted that the pastoral livestock supply chain in Kenya is constrained by inefficient and inadequate market information systems, resulting in weak coordination between producers and buyers. Furthermore, the volatile and rapidly changing nature of market information was found to significantly undermine pastoralists' bargaining power, limiting their ability to negotiate favourable prices and effectively engage with different actors within the livestock value chain.

Estimating the factors that influence market channel choice

Determinants of marketing channel choices for steers and heifers

The Multivariate Probit (MVP) model estimation results presented in Table 3 provide empirical evidence on the complex interplay of demographic, institutional, market, and shock-related factors shaping pastoralists' choice of livestock marketing channels during the drought period. The model demonstrates a good fit, with Wald χ^2 statistics of 2,681.9 for heifers and 860.27 for steers ($p < 0.001$), confirming the joint significance of the explanatory variables.

The analysis on socio-demographic characteristics revealed that variables such as the age and education level of the household head were positively and significantly associated with the likelihood of engaging with a broader range of market outlets, including traders, local butchers, and terminal markets. These findings suggest that more experienced and educated household heads are likely to possess enhanced negotiation skills, a better understanding of market dynamics, and a stronger ability to access or interpret market information (Kinyua et al., 2011; Muleta et al., 2019). The gender of the household head also influenced marketing channel preferences, particularly for heifers, where male-headed households were more inclined to use informal channels such as local butchers and markets. This may reflect gendered roles in decision-making and market engagement, particularly where men control livestock transactions in patriarchal household settings.

TABLE 3 Marketing channels for Heifers and Steers.

	Heifers					Steers				
	Trader	Local market	Local butcher	Slaughter house	Terminal markets	Traders	Local market	Local Butcher	Slaughter house	Livestock terminal markets
	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff
Age of the household head (HHH) (years)	0.021*** (0.005)	0.014** (0.005)	0.012** (0.004)	0.017 (0.008)	0.019* (0.0058)	0.011 (0.004)	0.017** (0.006)	0.010 (0.006)	0.005 (0.007)	0.009 (0.005)
Household size	0.048** (0.019)	0.023 (0.022)	−0.006 (0.022)	0.028 (0.023)	0.029 (0.0270)	0.044* (0.018)	0.080** (0.025)	0.004 (0.029)	0.057** (0.019)	0.047 (0.021)
Education years of the household head	0.046*** (0.013)	0.049*** (0.013)	0.006 (0.011)	0.025 (0.018)	0.078*** (0.0138)	0.066*** (0.011)	0.092*** (0.016)	0.069*** (0.017)	0.058*** (0.017)	0.050*** (0.013)
Gender of the household head (1 = Male, 0 = Female)	0.478 (0.211)	0.541* (0.204)	0.525* (0.190)	0.450 (0.226)	0.066 (0.1829)	0.183 (0.198)	−0.327 (0.215)	0.517 (0.324)	0.740* (0.365)	−0.271 (0.223)
Membership to common interest group/ association (1 = Yes, 0 = No)	−0.312* (0.160)	−0.406* (0.187)	−0.217 (0.135)	−0.109 (0.177)	−0.343* (0.216)	−0.437* (0.161)	−0.908** (0.300)	0.037 (0.215)	0.269 (0.194)	−0.182 (0.179)
Livestock marketing contract (1 = Yes, 0 = No)	0.204 (0.227)	−0.385 (0.257)	0.249 (0.233)	0.533* (0.266)	0.001 (0.308)	−0.400 (0.297)	0.277 (0.242)	−1.810*** (0.500)	−0.436* (0.413)	−0.523*** (0.255)
Access to credit (1 = Yes, 0 = No)	0.176* (0.088)	0.158 (0.096)	0.336* (0.163)	0.112 (0.097)	0.143 (0.139)	0.195 (0.123)	0.213 (0.117)	0.021 (0.308)	0.428*** (0.116)	−0.011 (0.178)
Access to extension services (1 = Yes, 0 = No)	−4.555*** (0.197)	−4.412*** (0.140)	−3.931*** (0.190)	−3.324*** (0.340)	−2.614*** (0.2758)	−0.340 (0.348)	0.136 (0.352)	−2.084* (0.771)	−0.427 (0.415)	−0.023 (0.388)
Received livestock marketing information (1 = Yes, 0 = No)	0.438*** (0.126)	0.392** (0.130)	0.338** (0.118)	0.231 (0.140)	0.524*** (0.1561)	0.227 (0.130)	0.292 (0.161)	−0.031 (0.178)	0.065 (0.163)	0.025 (0.162)
Migration of livestock in search of pasture and water (1 = Yes, 0 = No)	−0.509*** (0.137)	−0.289* (0.122)	−0.239** (0.111)	−0.257** (0.141)	−0.806*** (0.181)	−0.768*** (0.140)	−0.554** (0.175)	−0.591** (0.219)	−0.893*** (0.199)	−0.614*** (0.151)
Heifer and Steer TLU stocked	−0.001 (0.002)	−0.003 (0.002)	−0.001 (0.001)	−0.001 (0.001)	−0.001 (0.002)	0.005*** (0.001)	−0.005 (0.003)	0.004** (0.001)	0.005*** (0.001)	0.005*** (0.001)
TLU sold	−0.003 (0.019)	0.008 (0.023)	−0.018 (0.020)	−0.047 (0.022)	0.032 (0.0225)	−0.020 (0.025)	0.008 (0.023)	0.068* (0.024)	0.017 (0.022)	0.013 (0.020)

(Continued on following page)

TABLE 3 (*Continued*) Marketing channels for Heifers and Steers.

	Heifers					Steers				
	Trader	Local market	Local butcher	Slaughter house	Terminal markets	Traders	Local market	Local Butcher	Slaughter house	Livestock terminal markets
	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff
Household income (monthly in Ksh)	2.260 (0.002)	2.680 (0.002)	1.080 (0.002)	−6.700 (0.003)	3.760 (0.002)	2.220 (0.002)	3.620 (0.002)	−8.170* (0.006)	−1.590 (0.004)	5.140 (0.002)
Livestock production affected by disease outbreak (1 = Yes, 0 = No)	0.073 (0.128)	−0.108 (0.124)	0.135 (0.116)	−0.055 (0.156)	0.243* (0.1540)	0.193 (0.125)	−0.159 (0.157)	−0.410* (0.161)	−0.480** (0.166)	0.050 (0.169)
Livestock production affected by conflict (1 = Yes, 0 = No)	−0.645*** (0.151)	−0.505** (0.1552)	−0.117 (0.120)	−0.684*** (0.161)	−0.889*** (0.1866)	−0.636*** (0.154)	−0.508* (0.207)	−0.826** (0.272)	−0.714*** (0.216)	−0.845*** (0.184)
Livestock affected by drought (1 = Yes, 0 = No)	0.028 (0.255)	0.098 (0.273)	0.275 (0.280)	−0.197 (0.271)	−0.112 (0.2567)	−0.271 (0.242)	0.042 (0.354)	2.675*** (0.739)	0.441 (0.263)	0.304 (0.211)
Distance to the main market (KM)	−0.003 (0.002)	0.001 (0.001)	−0.001 (0.001)	−0.003 (0.002)	−0.008* (0.020)	−0.004* (0.001)	−0.001 (0.001)	0.001 (0.002)	−0.006 (0.003)	0.002* (0.001)
_cons	−3.187 (0.442)	−2.914 (0.430)	−2.455 (0.526)	−2.635 (0.609)	−3.242 (0.5257)	−2.132 (0.530)	−2.966 (0.666)	−5.991 (0.941)	−3.655 (0.609)	−2.794 (0.452)
Wald chi2 (90)	2,681.9					860.27				
Prob > chi2	0.0000					0.0000				
Number of obs	1,053									

Robust standard errors are in parentheses *P < 0.05, **P < 0.01, and ***P < 0.001.

Pastoralists often opt for traders coming to purchase at the farmgate because they offer instant cash, providing an essential lifeline for managing emergency needs such as medical bills and school fees. This is consistent with findings by Key et al. (2000), who note that smallholders often prefer low-return but low-cost market channels when faced with high fixed or search costs.

The study revealed that membership in Common Interest Groups (CIGs) was negatively associated with the use of local market and trader channels for steers and with local and terminal markets for heifers. Although this may seem counterintuitive, it aligns with observations by Ngutu et al. (2011), Pretty et al. (2020), and Rustinsyah (2019), who note that while CIGs can improve collective marketing outcomes, they may also restrict individual flexibility or prioritize formal market engagement over local sales. Njiru (2019) supports this view, highlighting the importance of co-managed market groups in ASAL regions for structured market access.

Extension service access was found to significantly reduce the likelihood of selling heifers across all marketing channels. This result reflects the advisory role of extension agents, who may counsel producers to delay sales or seek higher-value outlets. However, it may also point to a mismatch between advice and on-the-ground market options, particularly under distress conditions. In contrast, access to livestock marketing information significantly increased the likelihood of engaging with multiple channels when selling heifers, reinforcing the importance of timely and reliable market data. Yet studies by Kinyua et al. (2011) and Muleta et al. (2019) emphasize that pastoralists still face information asymmetries, especially regarding prices in secondary and terminal markets.

TABLE 4 Correlation coefficient of error terms obtained from the MVP model estimation.

	Heifer model			Steer model		
	Binary correlation coefficient	Robust standard errors	P-value	Binary correlation coefficient	Robust standard errors	P-value
rho21	0.458	0.068	0.000	0.560	0.067	0.000
rho31	0.339	0.087	0.000	0.476	0.074	0.000
rho41	0.326	0.081	0.000	0.623	0.100	0.000
rho51	0.678	0.057	0.000	0.479	0.080	0.000
rho32	0.827	0.060	0.000	0.704	0.051	0.000
rho42	0.707	0.052	0.000	0.730	0.071	0.000
rho52	0.863	0.058	0.000	0.853	0.022	0.000
rho43	0.729	0.050	0.000	0.899	0.059	0.000
rho53	0.602	0.105	0.000	0.799	0.038	0.000
rho54	0.442	0.074	0.000	0.796	0.053	0.000
Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0				Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0		
chi2 (10) = 390.343 Prob > chi2 = 0.0000				chi2 (10) = 360.39 Prob > chi2 = 0.0000		

The number of steers sold had a positive effect on the likelihood of using butcher outlets, likely due to quick liquidity needs during drought. Larger livestock holdings (measured in TLU) were positively associated with the use of trader, slaughterhouses, and terminal channels, suggesting that households with more livestock were better positioned to access structured markets, possibly due to their ability to offer bulk sales. These results are consistent with Lutta et al. (2021), who argue that maintaining large herds is essential for engaging in commercial livestock sales. This behaviour reflects what Key et al. (2000) identify as "threshold effects," where households avoid higher-return markets due to fixed access costs that cannot be recovered unless large volumes are sold.

Generally, the study observations confirm the critical role of shocks in shaping market participation. Conflict experiences, particularly cattle raiding, had a consistently negative effect on market channel engagement for both steers and heifers. These findings are in line with Roba et al. (2018), who argue that insecurity in ASAL regions reduces market access by increasing risk, disrupting transport, and limiting external trader penetration. Interestingly, disease outbreaks were found to increase the likelihood of selling heifers through terminal markets while reducing their sales through slaughterhouses and local butchers. This result can be explained by differentiated risk perceptions: pastoralists may view terminal markets as better able to absorb low-quality or at-risk animals, while formal processors like slaughterhouses may reject diseased stock due to regulatory oversight or public health concerns. In contrast, drought was found to significantly increase the use of butcher markets for steers, likely reflecting distress sales to meet immediate household needs. These findings align with those of Rass (2006) and Anno and Ameripus (2022), who emphasize the role of climatic stressors in accelerating livestock sales under suboptimal terms.

Livestock migration in search of pasture and water was significantly negatively associated with the use of nearly all marketing channels for both steers and heifers. This supports the idea that seasonal herd mobility constrains market participation, particularly when decision-making is not delegated to herders. These patterns are consistent with the findings of Ameleke et al. (2020), who noted that mobile livestock herds are often disconnected from market decision-making centres, limiting timely sales during favourable price periods.

Table 4 presents the results of the likelihood ratio (LR) test and the correlation coefficients of the error terms from the Multivariate Probit (MVP) model for heifer and steer marketing channel choices. The LR test results χ^2 (10) = 390.343 for heifers and χ^2 (10) = 360.39 for steers (both with $p < 0.0001$) strongly reject the null hypothesis that the error terms across the five market outlet equations are jointly uncorrelated. This confirms that the decisions to sell livestock through different marketing channels are not made independently of each other. More specifically, the null hypothesis that $\rho21 = \rho31 = \rho41 = \rho51 = \rho32 = \rho42 = \rho52 = \rho43 = \rho53 = \rho54 = 0$ is rejected at the 1% level for both models, validating the appropriateness of the multivariate specification over a series of univariate Probit models. This statistical

TABLE 5 Marketing channels for bulls and cows.

	Bulls					Cows				
	Trader	Local market	Local butcher	Slaughter house	Livestock terminal markets	Trader	Local market	Local Butcher	Slaughter house	Livestock terminal markets
Age of the household head (HHH) (years)	0.015* (0.005)	0.021*** (0.006)	0.014** (0.005)	0.014 (0.008)	0.017** (0.005)	0.010** (0.004)	0.020*** (0.004)	0.013** (0.005)	0.001 (0.006)	0.009* (0.004)
Household size	0.052* (0.019)	0.017 (0.025)	−0.038 (0.027)	0.009 (0.029)	0.027 (0.028)	0.053** (0.018)	0.041* (0.020)	−0.001 (0.022)	0.060* (0.025)	0.055** (0.017)
Education years of the household head	0.031* (0.013)	0.017 (0.014)	0.024 (0.015)	0.032 (0.020)	0.029 (0.016)	0.052*** (0.010)	0.056*** (0.011)	0.062*** (0.014)	0.041** (0.015)	0.047*** (0.010)
Gender of the household head (1 = Male, 0 = Female)	0.222 (0.199)	0.959*** (0.282)	0.626* (0.301)	0.822* (0.407)	0.276 (0.249)	0.351* (0.137)	0.544** (0.188)	0.286 (0.210)	0.347 (0.204)	0.399** (0.133)
Membership to common interest group/ association (1 = Yes, 0 = No)	−0.237 (0.147)	−0.298 (0.181)	0.146 (0.182)	0.329 (0.196)	−0.389 (0.202)	−0.905*** (0.124)	−0.650*** (0.144)	−1.188*** (0.277)	−0.521** (0.190)	−0.870*** (0.115)
Livestock marketing contract (1 = Yes, 0 = No)	−0.012 (0.333)	0.432 (0.283)	−0.081 (0.374)	−0.159 (0.396)	0.437 (0.278)	−0.399 0.217)	0.526* (0.201)	−3.304*** (0.345)	−0.423 (0.358)	0.286 (0.215)
Access to credit (1 = Yes, 0 = No)	0.146 (0.114)	0.044 (0.223)	0.147 (0.093)	0.140 (0.110)	0.145 (0.093)	−0.055 (0.318)	−0.225 (0.231)	0.191 (0.193)	0.240 (0.194)	−0.191 (0.209)
Access to extension services (1 = Yes, 0 = No)	0.713* (0.359)	0.627** (0.298)	0.057 (0.435)	−2.230*** (0.247)	0.092 (0.455)	0.121 (0.290)	0.394 (0.291)	−0.382 (0.440)	−0.681 (0.440)	0.430 (0.229)
Received livestock marketing information (1 = Yes, 0 = No)	−0.119 (0.145)	−0.002 (0.155)	−0.311* (0.192)	0.045 (0.186)	0.205 (0.174)	0.050 (0.098)	0.018 (0.116)	−0.201 (0.150)	−0.381** (0.157)	0.049 (0.096)
Migration of livestock in search of pasture and water (1 = Yes, 0 = No)	−0.342* (0.138)	−0.552*** (0.141)	−0.531** (0.189)	−0.397* (0.174)	−0.457* (0.183)	−0.477*** (0.100)	−0.233* (0.116)	−0.359** (0.144)	−0.263 (0.144)	−0.404*** (0.096)
Bulls/Cows TLU stocked	0.005*** (0.001)	0.001 (0.001)	0.003 (0.001)	0.005*** (0.001)	0.002 (0.001)	−0.008** (0.003)	−0.007* (0.002)	−0.008* (0.003)	−0.007* (0.003)	−0.008** (0.003)
Bulls/Cows TLU sold	0.024 (0.006)	0.003** (0.006)	−0.001** (0.001)	−0.027** (0.009)	−0.002 (0.007)	0.004 (0.014)	−0.012 (0.013)	0.024 (0.017)	0.022 (0.016)	0.003 (0.013)
Average price per livestock in KES	0.034 (0.043)	0.033 (0.042)	−0.028 (0.042)	0.005 (0.037)	0.009 (0.034)	0.001 (0.006)	−1.100 (0.007)	0.002*** (0.007)	0.002* (0.006)	0.006 (0.006)

(Continued on following page)

TABLE 5 (*Continued*) Marketing channels for bulls and cows.

	Bulls					Cows				
	Trader	Local market	Local butcher	Slaughter house	Livestock terminal markets	Trader	Local market	Local Butcher	Slaughter house	Livestock terminal markets
Household income (monthly in Ksh)	5.120 (0.003)	2.600 (0.003)	−5.030 (0.005)	−3.760 (0.004)	−5.260 (0.005)	4.240 (0.002)	3.380 (0.002)	−5.200 (0.004)	−0.001* (0.004)	1.400 (0.003)
Livestock production affected by disease outbreak (1 = Yes, 0 = No)	−0.138 (0.129)	−0.267* (0.141)	−0.034 (0.176)	0.128 (0.198)	0.161 (0.176)	0.360*** (0.097)	0.214 (0.110)	0.302* (0.143)	0.142 (0.156)	0.327*** (0.095)
Livestock production affected by conflict (1 = Yes, 0 = No)	−0.830*** (0.180)	−0.799*** (0.203)	0.208 (0.180)	−0.097 (0.178)	−0.146 (0.178)	−0.273** (0.105)	−0.540*** (0.128)	0.690*** (0.155)	0.489** (0.153)	−0.241* (0.103)
Livestock affected by drought (1 = Yes, 0 = No)	0.208 (0.301)	0.448 (0.351)	3.554*** (0.292)	−0.144 (0.432)	−0.062 (0.352)	−0.201 (0.197)	−0.040 (0.242)	0.212 (0.453)	−0.379 (0.267)	−0.180 (0.184)
Distance to the main market (KM)	−0.001 (0.001)	0.001 (0.001)	0.001 (0.001)	0.001 (0.002)	−0.001 (0.003)	−0.004*** (0.001)	−0.005*** (0.001)	−0.012*** (0.003)	−0.006*** (0.002)	0.014*** (0.002)
_cons	−2.986*** (0.587)	−3.698*** (0.611)	−6.288*** (0.594)	−4.023** (0.792)	−3.113*** (0.592)	−1.406*** (0.340)	−2.535*** (0.750)	−2.558*** (0.577)	−1.817*** (0.441)	−1.014*** (0.313)
Wald chi2 (90)	2,571.47					747.28				
Prob > chi2	0.000					0.000				
Number of obs	1,053									

Robust standard errors are in parentheses *P < 0.05, **P < 0.01, and ***P < 0.001.

dependence implies that modelling each marketing channel decision in isolation would introduce bias, and that pastoralists consider multiple marketing channel options simultaneously and interdependently.

The pairwise correlation coefficients (ρ) between the error terms of the MVP equations further highlight the interdependence. All estimated ρ values are positive and statistically significant, suggesting that pastoralists perceive different marketing channels of selling heifers and steers as complementary rather than substitutive. These findings suggest that pastoralists do not view these marketing outlets as isolated choices. Rather, decisions to sell heifers and steers through one channel are influenced by the availability, accessibility, or outcomes of others. For example, if the option to sell at a terminal market is constrained, the pastoralist may be more likely to turn to the trader or slaughterhouse. Similarly, certain combinations like butchers and slaughterhouses may be used concurrently depending on the animal condition, buyer preference, or transaction scale.

Determinants of marketing channel choices for bulls and cows

Table 5 reports the results of the Multivariate Probit (MVP) model examining the determinants of pastoralist households' marketing channel choices for bulls and cows. The Wald test statistics χ^2 (90) = 2,571.47 for bulls and χ^2 (90) = 747.28 for cows (both $p < 0.001$) indicate strong model significance and confirm that the set of explanatory variables jointly explains variation in the dependent variables. These results validate the appropriateness of the MVP model and highlight the interrelated nature of livestock marketing decisions.

The age of the household head positively influenced marketing choices across most channels for both bulls and cows, except for slaughterhouses (non-significant for cows and bulls). This suggests that older pastoralists draw on accumulated

experience and broader social networks when making sales decisions, particularly in local and informal markets. Similarly, years of formal education of the household head had a consistently significant and positive influence on marketing choices, especially for cows. Education likely enhances awareness of market dynamics and improves capacity for strategic decision-making, aligning with findings from Kinyua et al. (2011) and Muleta et al. (2019). In the pastoralist households, the gender of the household head also mattered in the decision to sell livestock. Male-headed households were significantly more likely to sell bulls through local markets, butchers, and slaughterhouses and cows through local markets, traders, and terminal markets. This underscores gendered market roles in pastoral economies, where men typically manage external livestock transactions.

The distance to main livestock markets negatively influenced the likelihood of using most market outlets for bulls, especially local markets, traders, slaughterhouses, and local butchers, suggesting that accessibility remains a key barrier to market participation. This supports prior evidence from Muleta et al. (2019) and van der Lee et al. (2020), who noted that producers prefer local outlets due to lower transport and time costs. Interestingly, distance had a positive effect on the choice of terminal markets for both bulls and cows, indicating that these are viewed as high-value or last-resort options, particularly when local demand or prices are inadequate. This finding aligns with Roba et al. (2019), who observed that larger traders often prefer to operate in centralized livestock markets, reducing their need to travel across dispersed production zones.

The number of TLUs stocked showed divergent effects: while higher livestock increased the likelihood of using traders and slaughterhouse for bulls, it reduced the probability of selling cows through any channel. This may reflect herd composition and production goals, as bulls are typically raised for cash sales or meat, while cows, especially lactating ones, are retained for household nutrition and long-term reproduction (Amwata et al., 2016; Nyariki and Amwata, 2019). Marketing contacts significantly increased the likelihood of selling cows through local markets, suggesting the importance of social ties and trust in local-level transactions (Dinku et al., 2019; Ng'asike et al., 2020).

Conflict had a strong negative impact on the use of local markets and trader channels for both bulls and cows, consistent with Roba et al. (2018), who highlight the disruptive role of insecurity in East African livestock markets. In contrast, conflict positively influenced the choice of slaughterhouse and local butchers when selling cows, possibly reflecting the need to sell quickly and locally in insecure contexts. Drought conditions significantly increased the likelihood of selling bulls through local butcher outlets, pointing to distress sales driven by resource scarcity and declining animal condition. This is in line with common drought coping strategies, where animals are sold before their market value deteriorates further.

Interestingly, disease outbreaks had mixed effects. For cows, the outbreak was positively associated with slaughterhouse use but negatively with local and trader markets. This supports Nyokabi et al. (2018), who argue that poorly enforced animal health regulations in informal markets increase the risk of circulation of diseased livestock.

Membership in Common Interest Groups (CIGs) had a strongly negative effect on the likelihood of selling cows through any market outlet. This suggests that CIGs may promote more deliberate, coordinated, or delayed sales, potentially consolidating supply for better bargaining power or price targeting (Kebebe, 2019; Liverpool-Tasie et al., 2020). These findings are echoed by Tripathy et al. (2020), who emphasize the role of group marketing in improving market access and enabling smallholders to overcome coordination failures.

Seasonal livestock migration in search of water and pasture negatively affected market participation across nearly all channels. This likely reflects decision-making constraints, where herding responsibilities are delegated to caretakers who do not participate in marketing (Ameleke et al., 2020). It also points to the logistical challenges of managing market access while prioritizing livestock survival in marginal environments.

The results in Table 6 presents the results of the likelihood ratio test in the MVP model for bulls and cows. The null hypothesis for the independence test was rejected for all models, as the likelihood ratio test (LR χ^2 (10) = 139.907, χ^2 > p = 0.0000) and (LR χ^2 (10) = 720.435, χ^2 > p = 0.0000) indicated significant error term independence. As a result, the usage of MVP is justified, demonstrating that the model captured broader impacts than a single equation-probit model; thus, the equations are interdependent. Similarly, all binary correlation coefficients, (Rho) presented in Table 6, are positive and mostly highly significant. This indicates that all five sets of marketing channel choices are complementary to each other.

Determinants of marketing channel choices for sheep and goats

Table 7 presents the results of the Multivariate Probit (MVP) model estimating the determinants of pastoralist households' choices of marketing channels for sheep and goats during the drought period. The model fit is statistically robust, as confirmed by Wald test statistics of χ^2 (90) = 419.77 for sheep and 404.52 for goats ($p < 0.001$), indicating that the explanatory variables jointly and significantly influence marketing channel decisions.

Access to livestock market information significantly influenced pastoralists' marketing channel preferences. For sheep, it positively affected the likelihood of using trader and terminal markets. For goats, it also significantly influenced the use of village markets, traders, and terminal markets. These results highlight the central role of timely and reliable market information in enabling informed decision-making, especially during droughts when household cash needs and animal

TABLE 6 Correlation coefficient of error terms obtained from the MVP model estimation.

	Bulls model			Cows model		
	Binary correlation coefficient	Robust standard errors	P-value	Binary correlation coefficient	Robust standard errors	P-value
rho21	0.628	0.067	0.000	0.465	0.048	0.000
rho31	0.260	0.096	0.014	0.314	0.070	0.000
rho41	0.257	0.092	0.003	0.250	0.071	0.000
rho51	0.326	0.095	0.000	0.644	0.038	0.000
rho32	0.393	0.124	0.006	0.629	0.046	0.000
rho42	0.453	0.115	0.000	0.714	0.049	0.000
rho52	0.506	0.088	0.000	0.886	0.017	0.000
rho43	0.563	0.099	0.000	0.693	0.059	0.000
rho53	0.311	0.117	0.002	0.711	0.043	0.000
rho54	0.237	0.110	0.001	0.724	0.043	0.000
Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0				Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0		
chi2 (10) = 139.907 Prob > chi2 = 0.0000				chi2 (10) = 720.435 Prob > chi2 = 0.0000		

offloading are high. This finding is in line with McPeak and Barrett (2001) and Kinyua et al. (2011), who report that information asymmetry often impairs pastoralists' ability to access distant or high-value markets.

Household income significantly influenced market channel use for goats: higher income increased the probability of selling through village and terminal markets. This suggests that more financially secure households can afford to engage in better-paying or distant markets, likely due to greater liquidity and reduced pressure to accept suboptimal local prices. The number of goats stocked was positively associated with use of the abattoir channel. This aligns with Inman et al. (2020), who emphasize that larger herd sizes provide producers the flexibility to liquidate livestock through formal markets without compromising herd sustainability. As reported by Roba et al. (2018), pastoralists frequently sell sheep and goats in large numbers to traders, who then connect them to distant or export-oriented markets.

Membership in Common Interest Groups (CIGs) significantly increased the likelihood of using abattoirs when selling sheep and terminal markets when selling both goats and sheep. These results are consistent with findings by Moyo et al. (2010), Moyo et al. (2010), and Roba et al. (2019), who argue that individual marketing is often inefficient in arid regions due to low volumes, high transaction costs, and spatial barriers. Group marketing enables aggregation, improves bargaining power, and reduces market entry costs. These dynamics are particularly important in SSA's ASALs, where market infrastructure is underdeveloped.

Interestingly, having a formal marketing contract was negatively associated with selling sheep to butchers and goats to traders. This finding reflects the challenges of trust and contract enforcement in informal pastoralist marketing systems. Pastoralists often enter into verbal or informal agreements that may be violated by traders, undermining confidence in future engagements. These findings echo the work of Lutta et al. (2021) and Muleta et al. (2019), who document frequent breaches of verbal and written agreements, contributing to market uncertainty and producer mistrust.

Access to extension services significantly increased the use of formal market channels such as terminal markets and slaughterhouses, especially for goats. This underscores the importance of advisory services in promoting market-oriented production behaviour and helping pastoralists transition from informal to formal markets. Similarly, access to credit had a mixed but generally positive influence on terminal market access, particularly for goats. This implies that financial flexibility enables producers to incur transport and transaction costs associated with structured markets.

The migration of livestock in search of pasture and water was negatively associated with nearly all marketing channels, particularly local and trader markets. This suggests that herd mobility, common in ASAL regions during dry spells, disrupts regular market participation, particularly when herders are away from homesteads or trade centres. Ameleke et al. (2020) similarly noted that delegated herding arrangements limit real-time market engagement, leading to missed price opportunities or default sales in distant locations.

TABLE 7 Marketing channels for Sheep and Goats.

	Sheep					Goats				
	Trader	Local market	Local Butcher	Slaughter house	Main market terminal	Trader	Local market	Local Butcher	Slaughter house `	Livestock market terminal
Age of the household head (HHH) (years)	0.008* (0.003)	0.019*** (0.004)	0.016*** (0.004)	0.001 (0.004)	0.013*** (0.003)	0.005 (0.003)	0.005 (0.004)	0.008 (0.004)	0.003 (0.004)	0.003 (0.003)
Household size	0.032* (0.016)	0.064*** (0.017)	−0.023 (0.019)	0.011 (0.019)	0.039* (0.015)	0.067*** (0.015)	0.087*** (0.017)	0.002 (0.017)	0.002 (0.017)	0.089*** (0.016)
Education years of the household head	0.016 (0.008)	0.059*** (0.010)	0.011 (0.011)	0.001 (0.011)	0.039*** (0.009)	0.005 (0.009)	0.033** (0.010)	−0.002 (0.011)	−0.009 (0.012)	0.011 (0.009)
Gender of the household head (1 = Male, 0 = Female)	−0.072 (0.107)	−0.310* (0.122)	0.096 (0.145)	−0.090 (0.142)	−0.187 (0.113)	−0.132 (0.107)	−0.159 (0.114)	0.129 (0.142)	0.013 (0.143)	−0.138 (0.107)
Membership to common interest group/ association (1 = Yes, 0 = No)	0.105 (0.093)	0.045 (0.110)	−0.392 (0.129)	0.154* (0.119)	0.344*** (0.096)	0.187 (0.091)	0.185 (0.102)	−0.235* (0.120)	0.144 (0.120)	0.346*** (0.094)
Livestock marketing contract (1 = Yes, 0 = No)	−0.326 (0.186)	0.001 (0.202)	−0.934* (0.364)	−0.434 (0.329)	0.054 (0.186)	−0.492* (0.192)	−0.151 (0.201)	−0.146 (0.240)	−0.387 (0.293)	−0.104 (0.187)
Access to credit (1 = Yes, 0 = No)	−0.044 (0.102)	−0.181 (0.140)	0.006 (0.129)	0.189 (0.149)	−0.338 (0.146)	0.294* (0.145)	−0.132 (0.120)	0.106 (0.102)	0.538** (0.171)	−0.160 (0.144)
Access to extension services (1 = Yes, 0 = No)	0.189 (0.217)	0.420 (0.277)	−0.416 (0.367)	0.332 (0.297)	0.214 (0.226)	0.716** (0.240)	0.586* (0.263)	0.088 (0.290)	0.692** (0.295)	0.608** (0.229)
Received livestock marketing information (1 = Yes, 0 = No)	0.161* (0.085)	0.146 (0.097)	−0.266* (0.116)	0.054 (0.112)	0.181** (0.092)	0.301*** (0.087)	0.250** (0.092)	0.063 (0.108)	−0.087 (0.118)	0.393*** (0.089)
Migration of livestock in search of pasture and water (1 = Yes, 0 = No)	−0.414*** (0.084)	−0.497*** (0.098)	−0.141* (0.104)	−0.187 (0.117)	−0.400*** (0.089)	−0.271*** (0.083)	−0.126 (0.093)	−0.014 (0.105)	−0.073 (0.117)	−0.072 (0.087)
Sheep/Goats TLU stocked	−0.002 (0.001)	−0.004** (0.001)	0.002 (0.001)	0.002 (0.001)	−0.004*** (0.001)	0.001 (0.001)	−0.005** (0.001)	0.001 (0.001)	0.003* (0.001)	−0.001* (0.001)
Sheep/Goats TLU sold	0.007 (0.011)	−0.011 (0.013)	0.025 (0.013)	−0.029* (0.013)	0.037** (0.012)	0.003 (0.004)	−0.001 (0.004)	0.001 (0.004)	−0.010 (0.007)	−0.009 (0.005)
Average price per livestock in KES	0.007 (0.004)	−0.001*** (0.005)	0.004 (0.005)	0.003 (0.005)	7.005 (0.004)	0.001 (0.004)	0.005 (0.004)	0.002*** (0.004)	0.002 (0.004)	0.004 (0.004)
Household income (monthly in Ksh)	0.002 (0.005)	−0.006 (0.004)	−0.009 (0.005)	−0.006 (0.006)	1.005 (0.002)	5.190 (0.003)	4.915** (0.001)	2.580 (0.002)	−2.360 (0.003)	4.630* (0.001)

(Continued on following page)

TABLE 7 (*Continued*) Marketing channels for Sheep and Goats.

	Sheep					Goats				
	Trader	Local market	Local Butcher	Slaughter house	Main market terminal	Trader	Local market	Local Butcher	Slaughter house `	Livestock market terminal
Livestock production affected by disease outbreak (1 = Yes, 0 = No)	0.113 (0.084)	0.008 (0.099)	0.336** (0.117)	0.043 (0.112)	−0.079 (0.092)	0.210** (0.085)	0.133 (0.093)	0.478*** (0.112)	0.374*** (0.121)	0.163* (0.087)
Livestock production affected by conflict (1 = Yes, 0 = No)	0.231** (0.089)	−0.171 (0.106)	0.267* (0.116)	0.532*** (0.123)	0.201* (0.096)	0.288*** (0.087)	−0.096 (0.102)	0.283* (0.110)	0.282* (0.116)	0.186* (0.091)
Livestock affected by drought (1 = Yes, 0 = No)	0.409* (0.199)	0.118 (0.216)	0.432 (0.262)	0.139 (0.268)	0.352 (0.209)	0.060 (0.198)	−0.197 (0.196)	−0.072 (0.235)	0.825 (0.416)	0.107 (0.214)
Distance to the main market (KM)	−0.001 (0.001)	−0.001 (0.001)	−0.008* (0.002)	−0.002 (0.001)	−0.010*** (0.001)	0.001 (0.001)	−0.001 (0.001)	−0.003 (0.001)	−0.002* (0.001)	−0.007*** (0.001)
_cons	−1.125*** (0.304)	−1.973*** (0.342)	−2.177*** (0.377)	−1.939*** (0.376)	−1.395*** (0.328)	−1.234*** (0.318)	−1.502*** (0.338)	−1.865*** (0.379)	−2.613*** (0.502)	−1.180*** (0.336)
Wald chi2 (90)	419.77					404.52				
Prob > chi2	0.000					0.000				
Number of obs	1,053									

Robust standard errors are in parentheses *P < 0.05, **P < 0.01 and ***P < 0.001.

Table 8 reports the likelihood ratio (LR) test results and the binary correlation coefficients from the Multivariate Probit (MVP) model, assessing the interdependence of marketing channel choices for sheep and goats. The results provide robust statistical support for the MVP framework, confirming that the decisions to engage in each of the five marketing outlets are not made in isolation but are instead interrelated. The likelihood ratio statistics χ^2 (10) = 927.83 for sheep and χ^2 (10) = 613.58 for goats, both with $p < 0.0001$, strongly reject the null hypothesis that the error terms across the market outlet equations are jointly uncorrelated. This validates the MVP model's application and suggests that separate univariate estimation of market channel choices would be biased and inefficient. In effect, pastoralist households consider multiple marketing options concurrently, and their decisions across these options are mutually influential.

Summary and conclusion

This study examined the determinants of pastoralist households' livestock marketing channel choices in Kenya's arid and semi-arid lands (ASALs), with a particular focus on how economic, demographic, institutional, and environmental factors shape market participation during drought conditions. Using a Multivariate Probit (MVP) model, Classification and Regression Tree (CART) analysis, and a feed-forward neural network, the study provides a multidimensional analysis of marketing behaviours across key livestock types, namely steers, heifers, bulls, cows, goats, and sheep, and the role of both formal and informal market information sources.

The findings reveal that access to livestock market information significantly increases the likelihood of pastoralists engaging with more formal and profitable market channels, such as traders and terminal markets. However, informal networks, particularly neighbours, family members, and local traders, remain the most influential sources of market intelligence, as confirmed by both neural network and CART analyses. These actors serve not only as information conduits but also as critical components of pastoralists' social safety nets, especially under conditions of mobility constraints and economic stress during drought. The study also identifies the emerging importance of mobile phone updates, particularly for access to trader and terminal markets, suggesting an evolving shift toward digital inclusion. Yet, radio and social media groups, though present, had limited influence in shaping actionable

TABLE 8 Correlation coefficient of error terms obtained from the MVP model estimation.

	Sheep			Goats		
	Binary correlation coefficient	Robust standard errors	P-value	Binary correlation coefficient	Robust standard errors	P-value
rho21	0.408	0.046	0.000	0.295	0.045	0.000
rho31	0.244	0.064	0.000	0.109	0.063	0.007
rho41	0.226	0.060	0.000	0.214	0.056	0.000
rho51	0.620	0.047	0.000	0.669	0.038	0.000
rho32	0.610	0.046	0.000	0.494	0.047	0.000
rho42	0.660	0.042	0.000	0.417	0.047	0.000
rho52	0.884	0.021	0.000	0.684	0.032	0.000
rho43	0.715	0.052	0.000	0.526	0.047	0.000
rho53	0.489	0.054	0.000	0.295	0.053	0.000
rho54	0.542	0.050	0.000	0.455	0.045	0.000
Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0				Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0		
chi2 (10) = 927.829 Prob > chi2 = 0.0000				chi2 (10) = 613.576 Prob > chi2 = 0.0000		

market behaviour, highlighting the need to improve content specificity and localization to enhance their effectiveness.

From a socioeconomic perspective, demographic factors such as age, gender, and education of the household head were significantly associated with preferences for structured markets, especially in the case of bulls and cows. Households with male or more educated heads were more likely to access higher-value outlets, underscoring the link between human capital and commercialization. The marketing decisions of pastoralists regarding sheep and goats are influenced by a complex interaction of market information access, group membership, shock exposure, and economic resources. Informal networks still dominate marketing decisions, but group participation and access to services significantly shape movement toward more formal and structured market channels. Addressing information gaps, improving enforcement of marketing contracts, and enhancing extension and credit access are critical to strengthening market participation and resilience among small-scale livestock producers.

Generally, the study observed that terminal markets consistently offered superior average prices; pastoralists did not prioritize these outlets, however, unless logistical support, liquidity, and favourable timing were assured. This supports the argument by other literature that improving pastoral market outcomes requires addressing infrastructure and institutional barriers, not just prices. Additionally, the study finds that pastoralist marketing behaviour is multi-objective and bundled, with decisions influenced not only by expected price returns but also by goals such as household provisioning, social obligations, and accessing credit services. Thus, market trips are part of a broader livelihood optimization strategy.

The likelihood ratio tests from the MVP model confirmed the interdependence of marketing channel choices, showing strong, positive correlations among outlet decisions. These findings underscore the need for multi-channel strategies and integrated market systems that reflect the lived realities of pastoral producers.

The study offers several actionable insights for policymakers, development partners, and market system stakeholders. First, market infrastructure development must be integrative, ensuring that enhancements to high-level terminal markets are aligned with improvements in feeder systems, such as village markets and trader networks. This holistic approach would enhance the flow and coordination of livestock across marketing tiers. Second, market information systems should be designed to capture and disseminate real-time, multi-channel price data, leveraging both digital technologies and traditional communication networks to reach a broad base of producers. Third, supporting livestock marketing cooperatives and Common Interest Groups (CIGs) is vital for strengthening market coordination and increasing pastoralists' bargaining power. Fourth, extension and advisory services should be tailored to reflect pastoralists' realities and empower them with market-relevant knowledge for strategic decision-making. Lastly, investments in mobile-based platforms and more reliable, trust-oriented marketing contracts can help reduce information asymmetry and improve coordination between buyers and sellers, ultimately enhancing transparency and fairness in the livestock market system.

Conclusion

In conclusion, the study underscores the complex, multi-layered nature of pastoralist marketing decisions, shaped by a mix of social networks, market access, environmental risks, and institutional structures. While informal systems remain vital, expanding access to reliable market information, strengthening collective marketing institutions, and investing in infrastructure are critical to improving price stability, market efficiency, and resilience in Kenya's ASAL regions.

Efforts by the Kenyan government and development partners to introduce livestock market information systems are commendable but have been constrained by poor rural communication infrastructure and challenges in timely information dissemination. Future interventions must therefore adopt a hybrid approach, one that strengthens traditional systems while integrating scalable, digital innovations.

Ultimately, livestock market development in ASALs must adopt a multidimensional approach—addressing supply-side challenges such as market distance and herd structure, as well as demand-side constraints like information asymmetry and security threats, especially in the face of growing pressures from climate variability and conflict.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Strathmore University InstitutionalScientific and Ethical Review Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

Authors Participated in the development of the manuscript, analysis and write up. All authors reviewed the results and approved the final version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/past.2025.14333/full#supplementary-material

References

Adicha, A., Girma, M., Darcho, D., and Kuse, K. (2021). Value chain analysis of goat in south omo zone, SNNPR, Ethiopia. *J. Agric. Econ.* 7 (1), 907–919. Available online at: https://d1wqtxts1xzle7.cloudfront.net/84861568/131020203061-libre.pdf?1650904373=&response-content-disposition=inline%3B+filename%3DValue_Chain_Analysis_of_Goat_in_South_Om.pdf&Expires=1746943041&Signature=GREpvvGwe5~O3n-GBG3mpmlV6HNMHH17zsG1NjQJi2epaUF8dSgvgKDjZyH4HaeT~i~9~yxQ0ygjAvh64jxVZzNc3TXtBb93Fc~o0r9AbOtx9Ljkls9xw2Lro3rd16TVMenv51jBBhp8XBvr6QCWC~rlst3CuwP9X7GA-WLAO-H5PyWwUWaKyKy9m69f17pRXCkZ5pTCyieGIZZKFTN6Jk08HyB6t-PpY-sz-VAkFjPGRettnIyRE8Y8R1TFBiCX3KTMJ1w0wiW~i5Vvd76kPmOyyRWzBZrBijIYiLMeJFetr4Pz6Un-aa4T8CXei3tGEk6mF2DlgH9SAxxQ1dSag__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA.

Aklilu, Y. (2008). *Livestock marketing in Kenya and Ethiopia: a review of policies and practice*. Available online at: https://fic.tufts.edu/wp-content/uploads/Livestock-Marketing-in-Kenya-2008.pdf.

Ameleke, G. Y., Haagsma, R., Karbo, N., and Mensah-Bonsu, A. (2020). The nature and drivers of contracts in cattle herding and management: the case of Ghana. *Pastoralism* 10, 13–17. doi:10.1186/s13570-020-00172-3

Amwata, D. A., Nyariki, D. M., and Musimba, N. R. (2016). Factors influencing pastoral and agropastoral household vulnerability to food insecurity in the drylands of Kenya: A case study of Kajiado and makueni counties. *J. Int. Dev.* 28 (5), 771–787. doi:10.1002/jid.3123

Anno, E. F. (2024). Marketing livestock and meat products from drylands: dries in Turkana, Kenya. *Marketing*, 3 (1), 01–16.

Anno, E. F., and Ameripus, M. E. (2022). Effects of internal and cross-border resource-based conflicts on livestock market performance in pastoral areas of karamoja, Uganda and turkana, Kenya. *Am. J. Environ. Resour. Econ.* 7 (3), 87–96. doi:10.11648/j.ajere

Anno, E. F., and Elenica, P. B. (2022). Impact of traders competitive rivalry on supply and demand relations in livestock markets in the drylands of Kenya. *Int. J. Bus. Econ. Res.* 10 (3), 99–109. doi:10.11648/j.ijber.20211003.13

Arinloye, D.-D. A., Pascucci, S., Linnemann, A. R., Coulibaly, O. N., Hagelaar, G., and Omta, O. S. (2015). Marketing channel selection by smallholder farmers. *J. Food Prod. Mark.* 21 (4), 337–357. doi:10.1080/10454446.2013.856052

Assan, N. (2022). Climate change impact on small-scale animal agriculture: livestock water and food security in africa. *Univers. J. Food Secur.*, 13–39.

AU (2013). Policy framework for pastoralism in Africa: securing, protecting and improving the lives, livelihoods and rights of pastoralist communities. Available online at: https://hdl.handle.net/10568/81080.

Baker, D., and Enahoro, D. (2023). *Livestock in development: challenges in policy advocacy and the role of economic analysis*. Available online at: https://pim.cgiar.org/files/2013/11/18_Baker_Enahoro_Synthesis.pdf.

Barrett, C. B. (2008). Smallholder market participation: concepts and evidence from eastern and southern Africa. *Food Policy* 33 (4), 299–317. doi:10.1016/j.foodpol.2007.10.005

Bassa, Z., and Woldeamanuel, T. (2019). Market structure conduct and performance of live cattle in Borana pastoral area: The case of Moyalle district, Oromiya regional state. *Int. J. Modern Trends Sci. Tech.* 5 (10), 29–37.

Behnke, R. H., Fernandez-Gimenez, M. E., and Turner, M. D. (2011). "Pastoral migration: mobile systems," in animal migration: A synthesis 10, 144.

Butt, B. J. H. E. (2015). Herding by mobile phone: technology, social networks and the "transformation" of pastoral herding in East Africa. *Hum. Ecol.* 43, 1–14. doi:10.1007/s10745-014-9710-4

Descheemaeker, K., Oosting, S. J., Homann-Kee Tui, S., Masikati, P., Falconnier, G. N., and Giller, K. E. (2016). Climate change adaptation and mitigation in smallholder crop–livestock systems in sub-saharan africa: A call for integrated impact assessments. *Reg. Environ. Change* 16, 2331–2343. doi:10.17352/2455-815X.000046

de Vries, M. (2019). *Vulnerability and adaptation strategies of dairy farming systems to extreme climate events in southwest Uganda: results of CSA-PRA workshops*. Available online at: https://edepot.wur.nl/468558.

Dinku, A., Abebe, B., Lemma, A., and Shako, M. (2019). Beef cattle value chain analysis: evidence from west hararghe zone of Ethiopia. *Int. J. Agric. Sci. Food Technol.* 5 (1), 077–087. Available online at: https://www.researchgate.net/profile/Adunea-Dinku/publication/337736296_Beef_cattle_value_chain_analysis_Evidence_from_West_Hararghe_Zone_of_Ethiopia/links/5e1d7633a6fdcc283771309f/Beef-cattle-value-chain-analysis-Evidence-from-West-Hararghe-Zone-of-Ethiopia.pdf.

Dizyee, K., Baker, D., and Rich, K. M. (2017). A quantitative value chain analysis of policy options for the beef sector in Botswana. *Agric. Syst.* 156, 13–24. doi:10.1016/j.agsy.2017.05.007

Eeswaran, R., Nejadhashemi, A. P., Faye, A., Min, D., Prasad, P. V., and Ciampitti, I. A. (2022). Current and future challenges and opportunities for livestock farming in west africa: Perspectives from the case of Senegal. *Agronomy* 12 (8), 1818. doi:10.3390/agronomy12081818

Fafchamps, M., Hill, R. V. J. E. D., and change, C. (2008). Price transmission and trader entry in domestic commodity markets. 56(4), 729–766.

FAO (2021). *OECD-FAO agricultural outlook 2021-2030*. Paris, France: FAO. Available online at: http://www.fao.org/3/cb5332en/cb5332en.pdf.

Fava, F. P., Nathaniel, D., Sina, J., Andrew, G., and Maher, B. (2021). *Building financial resilience in pastoral communities in Africa: lessons learned from implementing the Kenya Livestock Insurance Program (KLIP)*. Available online at: https://hdl.handle.net/10568/111681.

Francis Anno, E., and Beqiraj Elenica, P. (2021). Impact of traders competitive rivalry on supply and demand relations in livestock markets in the drylands of Kenya. *Int. J. Bus. Econ. Res.* 10 (3), 99–109. Availble online at: https://d1wqtxts1xzle7.cloudfront.net/79092781/10.11648.j.ijber.20211003.13-libre.pdf?1642638275=&response-content-disposition=inline%3B+filename%3DImpact_of_Traders_Competitive_Rivalry_on.pdf&Expires=1746957401&Signature=QdhImAd2mFF1fiY2EeEAJMCWsBoGTZMLCdwLzz~50sudM6cy3Fx3iYkk6En6t07Oh-kSP3OdBtAXQ1WR-xN7NtH7V9zQwq9uz32yOCzkDVTyI7H2XWq3k9zNGRXMGBt00FAVl1m5hT9Jjrgdmmyt8nNSUvbbQiZrK4ipfkUNE7X1BAQ5PFpgOyP9tQc8Pg3rM24~JFLfxoEMxZvubvSmTzOPcvFKBfhuMBHiCZJI8KvIpK6ugzVACOR7K~zLsIto6Am9SaOLv~EudGqt8LXqmrmYIKDrsoy1J3ZmgmXT~qRaa3Iaabp2y1~3AptG3V8L9TOgwZhxkBlUNnkwTfqGUg__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA.

Greene, W. H., and Hensher, D. A. (2003). A latent class model for discrete choice analysis: Contrasts with mixed logit. *Transp. Res. Part B Methodol.* 37 (8), 681–698. doi:10.1016/s0191-2615(02)00046-2

Guyo, R. H., Wang, K., Saito, M., Onodera, S. I., Shimizu, Y., and Moroizumi, T. (2024). Spatiotemporal shallow and deep groundwater dynamics in a forested mountain catchment with diverse slope gradients, western Japan. *Groundwater Sustainable Dev.* 25, 101150.

Hao, J., Bijman, J., Gardebroek, C., Heerink, N., Heijman, W., and Huo, X. (2018). Cooperative membership and farmers' choice of marketing channels–Evidence from apple farmers in Shaanxi and Shandong Provinces, China. *Food Policy* 74, 53–64. doi:10.1016/j.foodpol.2017.11.004

Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S., et al. (2013). The roles of livestock in developing countries. *animal* 7 (s1), 3–18. doi:10.1017/S1751731112001954

Homewood, K., Rowcliffe, M., De Leeuw, J., Said, M. Y., and Keane, A. (2019). Pastoralism, conservation and resilience: Causes and consequences of pastoralist household decision-making. *Agric. Resil.* 180, 180–208. doi:10.1017/9781107705555.010

Inman, E. N., Hobbs, R. J., and Tsvuura, Z. (2020). No safety net in the face of climate change: the case of pastoralists in Kunene Region, Namibia. *PloS one* 15 (9), e0238982. doi:10.1371/journal.pone.0238982

Jayne, T., Fox, L., Fuglie, K., and Adelaja, A. (2021). Agricultural productivity growth, resilience, and economic transformation in sub-Saharan Africa. *Assoc. Public Land-grant Univ. (APLU)*. Available online at: https://www.canr.msu.edu/resources/agricultural-productivity-growth-resilience-and-economic-transformation-in-sub-saharan-africa-implications-for-usaid.

Jenkins, A., Velandia, M., Lambert, D. M., Roberts, R. K., Larson, J. A., English, B. C., et al. (2011). Factors influencing the selection of precision farming information sources by cotton producers. *Agric. Resour. Econ. Rev.* 40 (2), 307–320. doi:10.1017/s106828050000808x

Kebebe, E. (2019). Bridging technology adoption gaps in livestock sector in Ethiopia: a innovation system perspective. *Technol. Soc.* 57, 30–37. doi:10.1016/j.techsoc.2018.12.002

Key, N., Sadoulet, E., and Janvry, A. D. J. A. j. o. a. e. (2000). Transactions costs and agricultural household supply response. *Am. J. Agric. Econ.* 82 (2), 245–259. doi:10.1111/0002-9092.00022

Kirui, L. K., Jensen, N. D., Obare, G. A., Kariuki, I. M., Chelanga, P. K., and Ikegami, M. (2022). Pastoral livelihood pathways transitions in northern Kenya: The process and impact of drought. *Pastoralism*, 12 (1), 23.

Kinyua, K. G., Yakub, G. A., Kamau, N. B., and Bett, H. K. (2011). 123 livestock marketing decisions among pastoral communities: the influence of cattle rustling in baringo district, Kenya. *Int. J. Agric. Manag. Dev. (IJAMAD)* 1 (1047-2016-85406), 123–137. doi:10.22004/ag.econ.164079

Kyeyamwa, H., Verbeke, W., Speelman, S., Opuda-Asibo, J., and Huylenbroeck, G. V. (2008). Structure and dynamics of livestock marketing in rural Uganda: Constraints and prospects for research and development. *J. Int. Food & Agribus. Mark.* 20 (4), 59–89. doi:10.1080/08974430802355523

Liverpool-Tasie, L. S. O., Wineman, A., Young, S., Tambo, J., Vargas, C., Reardon, T., et al. (2020). A scoping review of market links between value chain actors and small-scale producers in developing regions. *Nat. Sustain.* 3 (10), 799–808. doi:10.1038/s41893-020-00621-2

Luo, N., Olsen, T. L., and Liu, Y. (2021). A conceptual framework to analyze food loss and waste within food supply chains: an operations management perspective. *Sustainability* 13 (2), 927. doi:10.3390/su13020927

Lutta, A. I., Wasonga, O. V., Robinson, L. W., Nyangito, M. M., and Sircely, J. (2021). Determinants of livestock market participation among pastoral communities of Tana River County, Kenya. *Environ. Dev. Sustain.* 23, 7393–7411. doi:10.1007/s10668-020-00922-8

Mburu, S., Otterbach, S., Sousa-Poza, A., and Mude, A. (2017). Income and asset poverty among pastoralists in northern Kenya. *J. Dev. Stud.* 53 (6), 971–986. doi:10.1080/00220388.2016.1219346

McDermott, J. J., Staal, S. J., Freeman, H. A., Herrero, M., and Van de Steeg, J. (2010). Sustaining intensification of smallholder livestock systems in the tropics. *Livest. Sci.* 130 (1-3), 95–109. doi:10.1016/j.livsci.2010.02.014

McPeak, J. G., and Barrett, C. B. (2001). Differential risk exposure and stochastic poverty traps among East African pastoralists. *Am. J. Agric. Econ.* 83 (3), 674–679. doi:10.1111/0002-9092.00189

Mittal, S., and Mehar, M. (2016). Socio-economic factors affecting adoption of modern information and communication technology by farmers in India: analysis using multivariate probit model. *J. Agric. Educ. Ext.* 22 (2), 199–212. doi:10.1080/1389224X.2014.997255

Moyo, S., Swanepoel, F., and Stroebel, A. (2010). *The role of livestock in developing communities: enhancing multifunctionality*. Available online at: https://library.oapen.org/handle/20.500.12657/60623.

Muleta, B. G., Mummed, Y. Y., and Kurtu, M. Y. (2019). Assessment of beef cattle production and marketing practice in Eastern Oromia, Ethiopia. *Retrieved Ethiop*. Available online at: https://core.ac.uk/download/pdf/234684887.pdf.

Mutura, J. K., Nyairo, N., Mwangi, M., and Wambugu, S. K. (2015). Analysis of determinants of market channel choice among smallholder dairy farmers in Lower Central Kenya. *Int. J. Innovative Res. Dev.* 4 (10), 264–270. Available online at: https://ir-library.ku.ac.ke/server/api/core/bitstreams/59757b92-a416-4da8-93fa-e7fd0b9a265d/content.

Ndiritu, S. W. (2020). Beef value chain analysis and climate change adaptation and investment options in the semi-arid lands of northern Kenya. *J. Arid Environ.* 181, 104216. doi:10.1016/j.jaridenv.2020.104216

Ndiritu, S. W. (2021). Drought responses and adaptation strategies to climate change by pastoralists in the semi-arid area, Laikipia County, Kenya. *Mitig. Adapt. Strategies Glob. Change* 26, 10–18. doi:10.1007/s11027-021-09949-2

NDMA (2023). *National drought management authority strategic plan 2023 – 2027*. Available online at: www.ndma.go.ke.

Ng'asike, P. O. a., Stepputat, F., and Njoka, J. T. (2020). Livestock trade and devolution in the Somali-Kenya transboundary corridor. *Pastor. Res. Policy Pract.* 10, 1–14. doi:10.1186/s13570-020-00185-y

Ngutu, M., Lelo, F., Kosgey, I., and Kaufmann, B. (2011). Potential of pastoralist groups to manage small-stock marketing projects: a case study of groups in farakoren and malabot, Marsabit county, Kenya. *Livest. Res. Rural Dev.* 23 (1). Available online at: https://www.researchgate.net/profile/Brigitte-Kaufmann/publication/287462856_Potential_of_pastoralist_groups_to_manage_small-stock_marketing_projects_A_case_study_of_groups_in_Farakoren_and_Malabot_Marsabit_County_Kenya/links/574d5a4008aec988526a3c08/Potential-of-pastoralist-groups-to-manage-small-stock-marketing-projects-A-case-study-of-groups-in-Farakoren-and-Malabot-Marsabit-County-Kenya.pdf.

Njiru, J. W. a. N. (2019). *A Review of Co-managed Kenyan livestock markets: enhancing operational managementfor widespread adoption*. Available online at: https://a.storyblok.com/f/191310/561a0afcf4/kenya_co-management_final_june_20.pdf.

Nyariki, D. M., and Amwata, D. A. (2019). The value of pastoralism in Kenya: application of total economic value approach. *Pastoralism* 9 (1), 9–13. doi:10.1186/s13570-019-0144-x

Nyokabi, S., Birner, R., Bett, B., Isuyi, L., Grace, D., Güttler, D., et al. (2018). Informal value chain actors' knowledge and perceptions about zoonotic diseases and biosecurity in Kenya and the importance for food safety and public health. *Trop. animal health Prod.* 50, 509–518. doi:10.1007/s11250-017-1460-z

Ombasa, B. B. M., and Kiruthu, F. (2020). The influence of livestock policy and livestock productivity programs on pastoral production in Garissa County, Kenya. *Int. Acad. J. Soc. Sci. Educ.* 2 (2), 253–269. Available online at: https://www.iajournals.org/articles/iajsse_v2_i2_253_269.pdf.

Opiyo, F., Wasonga, O., Nyangito, M., Schilling, J., and Munang, R. (2015). Drought adaptation and coping strategies among the Turkana pastoralists of northern Kenya. *Int. J. Dis. Risk Sci.* 6, 295–309.

Osman, Y. A. (2024). Understanding the multiple factors in 'natural resource conflicts': a case study of local perspectives from Ewaso Ng'iro north river basin, Northern Kenya.

Pretty, J., Attwood, S., Bawden, R., Van Den Berg, H., Bharucha, Z. P., Dixon, J., et al. (2020). Assessment of the growth in social groups for sustainable agriculture and land management. *Glob. Sustain.* 3, e23. doi:10.1017/sus.2020.19

Rass, N. (2006). *Policies and strategies to address the vulnerability of pastoralists in sub-Saharan Africa*, 37. Rome: FAO, Pro-poor Livestock Policy Initiative (PPLPI) Working Paper Series. Available online at: https://assets.publishing.service.gov.uk/media/57a08c1c40f0b64974000fd8/PPLPIpb_wp37.pdf.

ReliefWeb. (2024). *Kenya: drought - 2014-2024*.

Roba, G. M., Lelea, M. A., Hensel, O., and Kaufmann, B. (2018). Making decisions without reliable information: the struggle of local traders in the pastoral meat supply chain. *Food Policy* 76, 33–43. doi:10.1016/j.foodpol.2018.01.013

Roba, G. M., Lelea, M. A., Hensel, O., and Kaufmann, B. (2019). Elusive profits: Understanding economic performance of local traders in the pastoral small ruminant value chain in northern Kenya. *Nomadic Peoples* 23 (1), 78–105. doi:10.3197/np.2019.23010

Rustinsyah, R. (2019). The significance of social relations in rural development: a case study of a beef-cattle farmer group in Indonesia. *J. Co-op. Organ. Manag.* 7 (2), 100088. doi:10.1016/j.jcom.2019.100088

Schaffnit-Chatterjee, C., Lanzeni, M. L., Ag, D. B., and Hoffmann, R. (2014). "Agricultural value chains in sub-saharan africa," in *From a development challenge to a business opportunity* (Frankfurt: Deutsche Bank Research), 1–28. Available online at: www.dbresearch.com.

Sulle, E. (2021). *Qualitative outcome study: the contribution of the CGIAR Research Program on Livestock to land use planning processes in Ethiopia, Kenya and Tanzania*.

Tiki, W., and Little, P. D. (2022). Deception and default in a global marketplace: The political economy of livestock export trade in Ethiopia. *J. Peasant Stud.* 50, 1431–1454. doi:10.1080/03066150.2021.2010714

Tripathy, K., Paliwal, M., and Singh, A. (2020). *Vamnicom working paper series*.

van der Lee, J., Oosting, S., Klerkx, L., Opinya, F., and Bebe, B. O. (2020). Effects of proximity to markets on dairy farming intensity and market participation in Kenya and Ethiopia. *Agric. Syst.* 184, 102891. doi:10.1016/j.agsy.2020.102891

Wafula, W. M., and Wasonga, O. V. (2021). "Analysis of actors and activities at dagoretti livestock market in nairobi city, Kenya," in *Paper presented at the joint XXIV international glassland and intrenational rangeland Kenya 2021, nairobi, Kenya*. Available online at: https://uknowledge.uky.edu/igc/24/3/9.

Wilhite, D. A., Sivakumar, M. V., and Pulwarty, R. (2014). Managing drought risk in a changing climate: the role of national drought policy. *Weather Clim. Extrem.* 3, 4–13. doi:10.1016/j.wace.2014.01.002