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Ruminant Livestock Production in Sudan: Systems, Genetic Resources, and Pathways to Sustainability under Climate and Conflict Stress

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ABSTRACT

Sudan has one of Africa's largest ruminant livestock populations, at around 105–110 million head of cattle, sheep, goats, and camels (circa 2020–2021), which underpin rural livelihoods, food security, and foreign-exchange earnings. This structured narrative review synthesizes current knowledge on Sudanese ruminant production across agro-ecological zones, integrating production systems, indigenous genetic resources, productivity and reproduction, disease burden, dairy and meat value chains, and the export economy, alongside the compounding effects of climate variability and the armed conflict that began in April 2023. Peer-reviewed literature and official statistics, mainly 2005–2026, were retrieved from international databases and analyzed thematically, with quantitative figures triangulated across independent sources and residual discrepancies reported as ranges. Ruminants contribute roughly one-third of agricultural gross domestic product, yet productivity remains low because of seasonal feed deficits, water scarcity, a heavy disease burden, weak veterinary and market infrastructure, largely undocumented crossbreeding, and unreliable population data. Indigenous Kenana and Butana cattle, Sudan Desert sheep, Desert and Nubian goats, and dromedary camels are valuable, climate-adapted genetic resources that remain under-exploited and increasingly at risk. The conflict sharply curtailed total livestock exports fell from about 4.77 million head worth US$830.6 million in 2024 to roughly 3.91 million head worth US$468.3 million in 2025 — and damaged slaughter capacity. We show how climate and conflict compound through shared mechanisms, and identify community-based breeding, improved feeding and animal-health systems, rangeland management, value-adding processing and traceability, climate adaptation framed around emission intensity, and reliable data and coherent policy as priorities for a resilient, sustainable ruminant sector.

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INTRODUCTION

Sudan possesses one of the largest ruminant livestock populations in Africa and the Arab world, and the sector is central to the country's food security, rural livelihoods and foreign-exchange earnings. Cattle, sheep, goats and camels supply milk and meat for domestic consumption and live animals and meat for export, while also providing draught power, transport, manure and a culturally embedded store of household wealth (1,2). Around ninety per cent of the national herd is owned and managed by smallholders, agro-pastoralists and mobile pastoralists, so ruminant production is a livelihood system as much as an economic sector (1,3).

Throughout this review, camels are discussed alongside true ruminants because they share the same rangelands, production systems and value chains; strictly, however, dromedaries are pseudo-ruminants with a three-compartment stomach, and this physiological distinction is flagged where it matters notably for feed efficiency and enteric-methane accounting in Section 3.8.

The livestock sub-sector contributes about one-third of agricultural gross domestic product and roughly two-fifths of agricultural employment, and it is consistently among the leading non-oil sources of foreign exchange (2,3). The country ranks first to third in Africa for cattle, sheep, goats and camels, a position built on vast rangelands and a deep stock of locally adapted breeds rather than on intensive inputs (1). This extensive, low-input character is both the sector's strength and its vulnerability: it confers resilience and low production costs, but it also locks animals into low, highly seasonal productivity, with direct consequences for household food security (6).

Despite their national importance, ruminant systems in Sudan have historically received limited policy attention and investment, and they continue to operate well below their genetic potential (1,4). Seasonal feed deficits, the low nutritive value of rangeland and crop residues, water scarcity, an entrenched disease burden, largely undocumented crossbreeding, weak veterinary and marketing infrastructure, and chronic gaps in reliable livestock data constrain output (1,2). These structural weaknesses now interact with two large-scale stressors that define the current operating environment: progressive climate change across the Sahelian and Sahelo-Saharan belt, and the armed conflict that erupted in April 2023 and has disrupted trade, markets and animal-health services.

The existing literature is rich on breed characterization, production-system description and the macro-economic role of livestock, but most syntheses predate the present conflict and treat climate and security stressors separately. This review's novelty lies in integrating these strands and, in particular, in making explicit how climate and conflict compound through shared mechanisms (Section 3.9) rather than acting as two independent shocks. Accordingly, the objectives are: (i) to characterise the agro-ecological distribution, population, production systems and genetic resources of Sudanese ruminants; (ii) to analyse the principal productivity constraints, dairy and meat value chains, and the structure of the export economy; (iii) to assess the compounding effects of climate variability and conflict, including the sector's environmental footprint; and (iv) to outline evidence-based pathways toward sustainability.

MATERIALS AND METHODS

This article is a structured narrative review conducted between January and May 2026. We retrieved peer-reviewed publications, official statistical bulletins, and institutional reports from Scopus, Web of Science, PubMed, and Google Scholar, supplemented by datasets and reports from the Food and Agriculture Organization (FAO), the Central Bank of Sudan, and the Sudanese Ministry of Animal Resources. Search strings combined the terms "Sudan", "ruminant", "cattle", "sheep", "goat", "camel", "production system", "agro-ecological zone", "indigenous breed", "pastoralism", "livestock export", "climate change" and "conflict" using Boolean operators.

Eligibility criteria. Records were eligible if they (i) reported empirical, statistical or policy information on Sudanese ruminants, or (ii) provided directly transferable evidence on tropical dryland ruminant production, climate adaptation or emissions used to frame the Sudanese case. Records were excluded if they were non-English without an accessible translation, addressed non-ruminant species without a comparative ruminant component, or duplicated data already captured by a more authoritative source. The primary window was 2005–2026; a small number of seminal earlier works were retained specifically for breed, zone, and system characterization, where they remain the authoritative primary description and have not been superseded (e.g., (13,34,40,42)), and this exception is stated explicitly rather than left implicit.

Screening and synthesis. After de-duplication, approximately 420 records were screened by title and abstract, of which about 150 were assessed in full and roughly 110 retained for synthesis (indicative counts; the final corpus is listed in the References). We organized retained sources thematically into eight domains: agro-ecological distribution; population and economy; production systems; genetic resources; productivity and constraints; dairy and meat value chains; export trade and conflict; and climate and sustainability.

Handling of conflicting figures. We triangulated quantitative estimates across independent sources. Where sources disagreed, we gave precedence to peer-reviewed studies, then to FAO datasets, then to national official statistics, and last to grey literature; irreconcilable discrepancies are reported explicitly as ranges rather than point estimates. Because population and wartime trade data are of contested reliability, the confidence attaching to the review's own quantitative claims is discussed as a distinct limitation in Section 3.10.

RESULTS AND DISCUSSION

Agro-ecological zones and the spatial distribution of ruminants

Sudan spans a steep north–south rainfall gradient, from hyper-arid desert in the north to high-rainfall savanna in the south-west, and this gradient governs where each ruminant species is concentrated (Table 1) (40). The desert and semi-desert zone (under about 300 mm of rainfall per year) in the north and east is the domain of camels and Desert goats, with Desert sheep moving through seasonally. The low-rainfall savanna (about 300–800 mm), which includes the Butana plains, Kordofan, and Gedaref, is the heartland of the national herd, supporting dairy zebu breeds along with large flocks of sheep and goats (24,25).

Table 1. Agro-ecological zones of Sudan and their dominant ruminant species.

Agro-ecological zone	Rainfall (mm/yr)	Main location	Dominant ruminants
Desert & semi-desert	< 300	Northern, eastern	Camels, Desert goats, Desert sheep
Low-rainfall savanna	300–800	Butana, Kordofan, Gedaref	Kenana/Butana cattle, sheep, goats
High-rainfall savanna	800–1,500	S & SW (Darfur, south)	Baggara cattle, sheep, goats
Flood region & Nile valley	≈ 100–500 + irrigation	Along Blue/White Nile	Cattle, peri-urban dairy
Montane (Jebel Marra, Nuba, Red Sea Hills)	up to ≈ 1,000 (orographic)	Western & eastern uplands	Goats, cattle, sheep

Note: Rainfall bands for the flood region and montane zones are indicative; local values are strongly modified by irrigation and orographic effects, respectively. Source: synthesized from ecological zonation and rangeland literature (25,40) and breed-distribution studies (15,24).

The high-rainfall savanna of the south and south-west supports Baggara cattle and small ruminants, while the flood region and Nile valley host cattle and most peri-urban dairy activity. Montane areas such as Jebel Marra, the Nuba Mountains and the Red Sea Hills carry mixed holdings dominated by goats. The Greater Kordofan and Greater Darfur regions together hold the largest livestock numbers, but field surveys repeatedly diverge from official figures, underscoring the need for updated, spatially explicit livestock data to guide planning, disease control and rangeland management (3,37).

Ruminant population and contribution to the national economy

As of the most recent reasonably complete FAO and national estimates (circa 2020–2021), the national herd stands at roughly 105–110 million head; later unofficial figures circulated through late 2025 range as high as 111–140 million, a spread that itself reflects the weakness of the census system (3,4). The species breakdown in Table 2 and Figure 1 corresponds to this circa-2021 baseline: approximately 31 million cattle, 40 million sheep, 32 million goats and 4.8 million camels (sum ≈ 107.8 million). Small ruminants thus account for about two-thirds of all ruminant heads and dominate the live-animal export trade (24,37).

Table 2. Estimated ruminant populations, roles and distribution in Sudan (circa 2020–2021).

Species	Population (M head)	Share of total (%)	Principal roles	Dominant regions
Cattle (zebu)	≈ 31	≈ 29	Milk, meat, draught, savings	Central & southern belts
Sheep	≈ 40	≈ 37	Meat, live export, savings	Kordofan, Darfur, central
Goats	≈ 32	≈ 30	Milk, meat, food security	Kordofan, Darfur, arid zones
Camels	≈ 4.8	≈ 4	Milk, meat, transport, export	Northern & eastern arid zones

Note: Figures are indicative and synthesized from FAO and national sources for circa 2020–2021; official and field estimates differ materially (3,4,37).

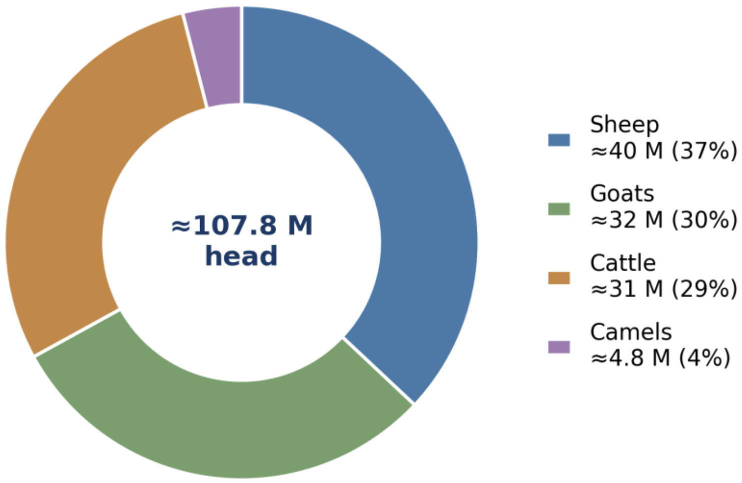

Figure 1. Indicative composition of the Sudanese ruminant herd by species (circa 2020–2021). Source: compiled from FAO and national statistics (3,37).

A persistent paradox of the sector is the gap between its macro-economic weight and the modest productivity and welfare of individual animals and producers, a gap rooted in under-investment, thin service provision and unreliable data that hampers planning (1,4). Closing it is less a matter of herd size, which is already very large, than of raising output per animal and capturing more value along the chain.

Production systems

Sudanese ruminants are reared along a continuum of extensive systems (Table 3). Mobile and transhumant pastoralism predominates in the drier rangelands, where herders move seasonally between wet-season grazing and dry-season refuges, exploiting spatial and temporal variability as a deliberate production strategy rather than a constraint (22,23). Far from being a residual or backward practice, this managed opportunism is an efficient response to unpredictable dryland environments and remains the backbone of national offtake (23). Agro-pastoral systems, common in the rain-fed and irrigated belts of central Sudan, integrate cropping with cattle, sheep and goat keeping, so that crop residues and manure are exchanged within the same household economy; such mixed crop–livestock systems are widely regarded as a high-return, resource-efficient pathway in smallholder settings (5,12), and in these areas cattle commonly make up more than seventy per cent of the herd's tropical livestock units, with cows the dominant class (12). Sedentary and peri-urban dairy units, including some crossbred stock, supply fresh milk to towns but remain a minor share of total numbers (1,43).

Table 3. Principal ruminant production systems in Sudan and their characteristics.

System	Mobility	Main species	Feed base	Distribution
Nomadic pastoral	High	Camels, sheep, cattle	Natural rangeland	Arid/semi-arid
Transhumant	Seasonal	Cattle, sheep, goats	Rangeland + residues	Savanna belts
Agro-pastoral	Low	Cattle, sheep, goats	Crop residues + range	Central rain-fed/irrigated
Sedentary peri-urban dairy	Settled	Cattle (some crossbred)	Cut-and-carry + concentrate	Around towns

Source: compiled from production-system and pastoralism literature (1,22,23).

Across these systems, feeding relies heavily on natural rangeland, crop residues and agro-industrial by-products of generally low and seasonally fluctuating nutritive value, and water is frequently drawn from seasonal pools and hand-dug reservoirs known locally as hafeers (1,22). Large wet-season feed surpluses produced in distant breeding areas are often underused or wasted because of limited conservation, transport, and storage, while dry-season deficits drive weight loss, reduced fertility, and mortality (1). The mobility that underpins these systems is increasingly squeezed by the expansion of mechanized rain-fed agriculture, which has encroached on communal rangelands and blocked migratory corridors in eastern and central Sudan, raising the risk of resource-based conflict (25,26,47).

Indigenous genetic resources and breed characterization

Sudan's ruminants comprise a rich pool of indigenous breeds adapted to heat, water deprivation, long dry seasons and trekking (Table 4). Among cattle, the Kenana and Butana are dairy zebu of central Sudan; the Butana, kept by pastoralists and agro-pastoralists on the Butana plains between the Blue Nile and Atbara rivers, can yield on the order of 1,600 kg of milk per lactation under improved station management and is regarded as one of the most promising indigenous dairy breeds for semi-arid conditions (11,14). Western Baggara cattle are valued for meat and resilience, and the older literature on Sudanese cattle confirms the long history of selection for survival under harsh conditions (34). Genomic analyses have detected signatures of selection in Kenana and Butana related to thermotolerance and immune function, underscoring their value as adapted germplasm (15).

Table 4. Major indigenous ruminant breeds of Sudan and their adaptive and production traits.

Species	Main indigenous breeds/types	Adaptive and production traits
Cattle	Kenana, Butana, Baggara (Western)	Dairy zebu adapted to semi-arid heat and long dry seasons; Butana yields up to ≈ 1,600 kg milk/lactation on station; thermotolerant; able to use low-quality feed and limited water.
Sheep	Sudan Desert sheep (Shugor, Watish, Dubasi, Ashgar, Garag); Sawakni	Long-legged hair sheep prized for meat; Sawakni preferred in Gulf export markets for size and meat quality; lamb under extensive rangeland conditions.
Goats	Sudan Desert goat, Nubian, Taggar	Highly resilient browsers suited to arid, drought-prone zones; Nubian noted for milk; provide household milk, meat and a liquid asset.
Camels	Rufa'a, Anafi, Bishari, Kabashi	Dromedaries adapted to desert and trans-desert trekking; sources of milk, meat and transport; rising per-head export value.

Source: compiled from breed-characterization studies (11,14,15,18,20,45).

Sudan Desert sheep, comprising subtypes such as Shugor, Watish, Dubasi, Ashgar and Garag, are long-legged hair sheep prized for meat; the Sawakni type is particularly sought after in Gulf markets for its size and meat quality (20). Sudan Desert and Nubian goats are highly resilient browsers suited to arid zones, with the Nubian noted for milk, while the dromedary ecotypes Rufa'a, Anafi, Bishari and Kabashi are adapted to desert transport and to milk and meat production (18,45). Table 5 summarises indicative production and reproduction parameters for the four species; they show the comparatively slow reproductive cycle and long generation interval of cattle and camels compared with the faster turnover of small ruminants, which partly explains why sheep and goats dominate marketed offtake.

Table 5. Indicative production and reproduction parameters of Sudanese ruminants under traditional (extensive) management.

Parameter	Cattle	Sheep	Goats	Camels
Age at first parturition (mo)	40–48	16–20	14–18	48–60
Parturition interval (mo)	14–21	8–12	8–10	20–26
Litter size (n)	1.0	1.0–1.2	1.3–1.8	1.0
Mature live weight (kg)	250–350	30–50	25–40	350–550
Milk yield/lactation (kg)	500–1,700	—	100–250	1,000–2,700†

Parameter	Cattle	Sheep	Goats	Camels
Lactation length (mo)	7–10	—	3–5	9–18

Values are indicative ranges that vary widely by breed, system and season; compiled from breed-characterization and on-farm studies (11–14,18,20,21,34,45). Live-weight ranges are consistent with predictive studies on Sudanese zebu (21). † The upper end of the camel range reflects well-fed or station conditions; traditionally managed herds typically yield ≈ 1,000–1,800 kg/lactation (18,45).

These resources are, however, threatened by largely undocumented crossbreeding with exotic stock, pursued to raise milk yield in the absence of organized breeding programs, which risks diluting locally adapted alleles and eroding genetic diversity (11,14,17). National data on the extent of crossbreeding are lacking; herd-level studies nonetheless indicate that crossbred animals form an appreciable and rising share of peri-urban and near-urban dairy cattle, commonly reported in the range of roughly one-tenth to one-third of such herds while remaining marginal in pastoral herds, so the threat is concentrated in and around towns rather than uniform across the sector. Reported heritabilities for milk-yield traits in Butana and Kenana are moderate, around $h^2 \approx 0.20$–0.35 in station and on-farm studies, indicating that structured within-breed selection could deliver genetic progress while conserving adaptation (11,14,16).

Productivity and production constraints

Feed and nutrition

Nutrition is the foremost constraint. Feed is chronically deficient relative to need, and the available rangeland and crop residues are fibrous and low in protein and energy, so that growth, reproduction and milk yield fall well below genetic potential (1,4). The core problem is temporal mismatch: abundant but low-quality wet-season biomass followed by acute dry-season scarcity, with little conservation to bridge the gap. Strategic supplementation of grazing Desert sheep with energy and protein sources has been shown to improve performance, indicating clear scope for low-cost feeding interventions, such as residue treatment, urea-molasses supplementation, and better use of agro-industrial by-products where inputs are accessible (44).

Water resources

Water scarcity compounds the feed problem, particularly in the dry season and during drought years, and the distribution of watering points is a primary determinant of grazing pressure and migration routes (22,35). Over-concentration around the few permanent water sources contributes to localized rangeland degradation and to friction between herders and cultivators, so water-point planning is simultaneously a productivity, environmental and conflict-mitigation issue.

Animal health and the disease burden

Endemic and transboundary diseases impose heavy and recurrent losses (Table 6). Peste des petits ruminants, foot-and-mouth disease, brucellosis, paratuberculosis, contagious caprine pleuropneumonia and tick-borne theileriosis cause mortality, abortion and trade restrictions, while veterinary services, vaccine cold chains and diagnostic capacity remain thin and unevenly distributed (27,28,29,30). Several of these diseases are zoonotic or trade-sensitive, so their control is simultaneously a public-health and export-competitiveness issue a linkage the conflict has sharpened by degrading the cold chains and surveillance on which control depends.

Table 6. Selected major diseases affecting ruminant production in Sudan.

Disease	Type/agent	Species affected	Main impact
Peste des petits ruminants	Viral	Sheep, goats	High mortality, trade bans
Foot-and-mouth disease	Viral	Cattle, sheep, goats	Production loss, export restriction
Brucellosis	Bacterial	All ruminants	Abortion, zoonosis
Tropical theileriosis	Tick-borne protozoan	Cattle	Mortality, weight loss
Contagious caprine pleuropneumonia	Bacterial	Goats	Respiratory mortality
Paratuberculosis	Bacterial	Cattle, small ruminants	Chronic wasting, low yield
Internal & external parasites	Helminths, ticks	All ruminants	Reduced growth and output

Source: compiled from disease surveillance and review literature (27–30).

Reproduction, breeding management and institutions

Poor nutrition and the absence of organized breeding and recording depress reproductive performance, leaving long parturition intervals and late first calving (Table 5). At the institutional level, limited and costly credit, weak extension, poor market access and unreliable livestock statistics restrict producers' ability to invest and to respond to price signals, perpetuating the low-input, low-output equilibrium (1,4). The result is a system in which each constraint reinforces the others, so that isolated interventions tend to disappoint unless feed, health, breeding and market access are addressed together.

Dairy and meat production and value chains

All four ruminant species contribute milk, but much of it is consumed within the producing household or used to rear offspring, so its economic contribution is easily overlooked; even so, national milk output runs to several million tonnes annually, and the country nonetheless imports milk powder and processed dairy products to meet largely urban demand (1,43). Camel milk is of growing interest for its nutritional and therapeutic properties and for arid-zone food security (41,45). Marketed dairy is constrained by the lack of cold chains, processing and quality control along the chain (43).

Meat is the principal commercial output. Sheep and goats supply most marketed red meat and dominate live exports, while cattle and camels add carcass weight and value;

Sudanese Desert sheep are recognized for favorable carcass and meat-quality attributes, which underpins their premium in Gulf markets (20,42). Capturing more of this value domestically through hygienic slaughter, chilling and certification rather than live-animal export is a recurring policy aspiration that the current conflict has made both harder and more urgent.

Export trade and the impact of the armed conflict

Livestock exports are a strategic pillar of Sudan's external trade. In normal years, the country exports millions of live animals, chiefly sheep, to Saudi Arabia and camels to Egypt and Libya, together with chilled and frozen meat to Gulf markets; sheep typically account for the large majority of the value of live-animal exports, and the per-head value of exported camels has risen sharply (2,24). Live-animal exports to Saudi Arabia alone were valued at about US$715 million in 2023 (36).

The conflict that began in April 2023 has severely disrupted this trade. Export slaughterhouses in and around Khartoum, including the Kadero and Karari facilities, went out of service, and trade routes from Darfur and central Sudan to Port Sudan became contested, with warring parties imposing informal levies and seizing animals. Credible reports indicate that armed actors have taxed and diverted livestock and gum-arabic trade, partly to finance conflict (48,50); the precise scale is hard to verify under wartime conditions, and these estimates should be read with corresponding caution. New export-oriented facilities, such as a Saudi-funded chilled-meat plant in River Nile State, were opened to partially substitute for lost capacity. Even so, total livestock exports fell from about 4.77 million head worth US$830.6 million in 2024 to roughly 3.91 million head worth US$468.3 million in 2025 (Table 7, Figure 2). Sheep export value was US$238 million for the full year 2024; the corresponding first-half figure for 2025 was US$165 million (January–June), so 2025 was tracking well below the 2024 annual level on a comparable half-year basis rather than falling from 238 to 165 over a full year (36,37).

Sector-wide losses for 2025 have been estimated at around US$1 billion. This figure is larger than total realized export earnings because it is not confined to foregone exports: on the reported values, the direct export shortfall relative to 2024 is about US$362 million, to which distress sales and herd depletion, damage to slaughter and market infrastructure, and lost throughput and services must be added to reach the order-of-magnitude US$1 billion estimate (48,50).

Table 7. Sudanese livestock export indicators, 2024–2025.

Indicator	2024	2025
Total live-animal & meat exports (M head)	4.77	3.91
Total export value (US$ million)	830.6	468.3
Sheep export value (US$ million)	238 (full year)	165 (Jan–Jun)
Estimated sector-wide loss (US$ billion)	—	≈ 1.0

Note: The 2024 and 2025 sheep values cover different periods (full year vs January–June) and are not directly comparable. Source: Sudanese Ministry of Animal Resources and Central Bank of Sudan (36,37).

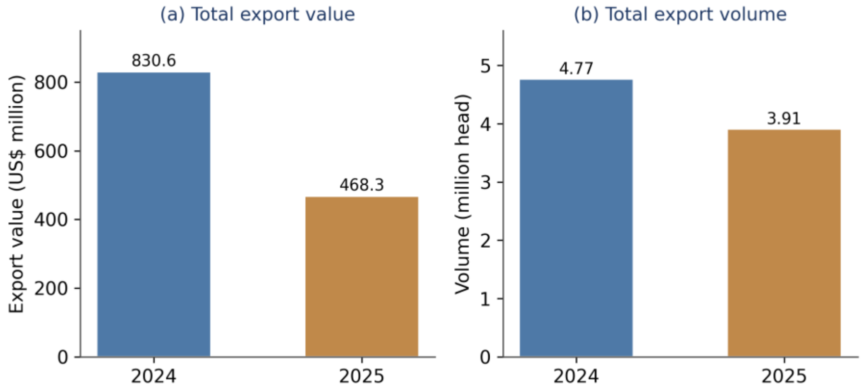

Figure 2. Sudanese total live-animal and meat export (a) value and (b) volume, 2024–2025. Source: compiled from Sudanese Ministry of Animal Resources and Central Bank of Sudan data (36,37).

These figures point to a strategic reorientation now under discussion in Sudan: a shift from exporting live animals toward exporting chilled and processed meat in order to capture added value, rehabilitate facilities to international standards, and strengthen quarantine, animal-health certification and traceability so that the country can re-enter and diversify its export markets (19,37). Whether this can be achieved depends heavily on the conflict's trajectory and the restoration of secure transport corridors.

Climate change, environmental footprint and adaptation

Layered over these structural constraints is climate change: rising temperatures and heat stress, more variable rainfall and recurrent drought reduce feed and water availability and directly impair production and reproduction, with small ruminants and camels generally more resilient than cattle (7,8,9,32,33,46). Sudan’s extensive systems are highly exposed because they depend on rain-fed rangeland, yet they also offer adaptive flexibility through mobility and species diversification (10,31).

At the same time, ruminants are a source of greenhouse-gas emissions, chiefly enteric methane, and grazing systems in low-productivity settings tend to have a high emission intensity per unit of product (38,39). Because camels are pseudo-ruminants with a distinct fermentation physiology, their per-animal methane output should not be equated with that of true ruminants when compiling sector inventories. Improving feed quality, animal health and reproductive efficiency raises output per animal and therefore lowers emission intensity, aligning productivity gains with climate-change mitigation (38,49). A clear evidence gap, however, is the absence of Sudan- or Sahel-specific emission-intensity estimates: the mitigation argument here rests on global and regional analyses, and generating national figures is itself a research priority that this review helps to identify. Framing Sudanese ruminant development around emission intensity, rather than absolute herd size, reconciles the livelihood imperative of large pastoral herds with the global sustainability agenda.

Compounding effects of climate variability and armed conflict

This review's central contribution is to treat climate variability and armed conflict not as two separate shocks but as stressors that compound through a shared set of mechanisms (Figure 3). Four channels are especially important. First, both narrow the mobility on which dryland production depends: climate variability shifts and shortens the windows of usable grazing, while insecurity, checkpoints, and contested corridors physically block the seasonal movements that let herders track scarce forage, so the adaptive strategy that normally buffers climate stress is disabled precisely when it is most needed (22,25,35). Second, both drive feed and water market failure: drought raises the cost of supplementary feed while conflict disrupts its transport and trade, turning a manageable dry season into a subsistence crisis for herds (1,48). Third, both erode animal-health capacity: heat and drought raise disease pressure, while conflict has degraded veterinary services, vaccine cold chains, and surveillance, so outbreaks that once would have been contained now spread and close export markets (27,30,48). Fourth, both force destocking: households sell or lose animals under drought and under looting or distress alike, depleting the breeding base and the genetic resources described in Section 3.4.

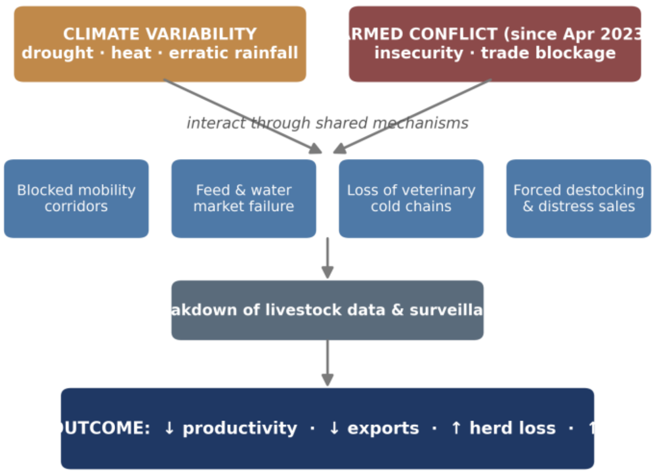

Figure 3. Conceptual framework of how climate variability and armed conflict compound through shared mechanisms to depress the Sudanese ruminant sector.

Underlying all four channels is a fifth, cross-cutting effect: the breakdown of livestock data and surveillance, which removes the information needed to target relief, control disease and plan recovery. The practical implication is that interventions designed for either stressor in isolation will under-perform; feed reserves, mobile veterinary services, protected migration corridors and rapid data systems are valuable precisely because they act on mechanisms shared by both climate and conflict, and therefore yield resilience dividends under either.

Data reliability and confidence

A recurring theme across Sections 3.1, 3.2 and 3.7 is the unreliability of the underlying data, and it is important to state plainly what this means for the review's own quantitative claims. Population totals rest on an aging and incomplete census system and diverge widely between official and field sources; wartime trade figures are collected under conditions that impede verification; and estimates of conflict-related loss necessarily combine measured and inferred components. Accordingly, the numerical claims in this review are best read as orders of magnitude and directions of change rather than precise values, and the ranges reported throughout are deliberate rather than a stylistic choice. This uncertainty does not weaken the central argument that the sector is large, valuable, under-productive, and now acutely stressed, but it does make re-establishing reliable, spatially explicit livestock data a first-order priority rather than a technical footnote.

Pathways toward sustainable ruminant development

Evidence across the reviewed literature converges on several complementary priorities. First, conservation and genetic improvement of indigenous breeds through community-based breeding programs rather than undocumented crossbreeding can raise productivity while safeguarding adapted germplasm, as demonstrated by work on Butana cattle (14,16). Second, feed and rangeland strategies conservation of wet-season surpluses, treatment and strategic supplementation of crop residues, and participatory rangeland and corridor management can narrow seasonal deficits and reduce conflict over grazing land (1,25,26,44). Third, strengthening animal-health systems, vaccine cold chains and disease surveillance under a one-health framing would cut losses and remove barriers to export (27,30).

Fourth, investment in slaughterhouse rehabilitation, traceability and quality assurance is needed to add value, meet importing-country standards and rebuild trade after the conflict (19,24,37). Fifth, climate adaptation favoring heat-tolerant small ruminants and camels where appropriate, improving water harvesting, and integrating crop–livestock systems can build resilience while lowering emission intensity (8,9,10,38). Underpinning all of these is the need for reliable, spatially explicit livestock data and coherent, adequately financed policy, without which planning, investment and disease control remain guesswork (1,4). Pursued together, these measures offer a credible route to a more productive, equitable and sustainable ruminant sector capable of withstanding the dual pressures of a changing climate and post-conflict recovery.

CONCLUSION

Sudan's ruminant sector combines exceptional scale and strategic economic importance with persistently low productivity and acute vulnerability. Its indigenous cattle, sheep, goat and camel breeds, distributed across a wide agro-ecological gradient, are valuable, climate-adapted genetic resources, but they are under-exploited and increasingly at risk. The armed conflict since April 2023, superimposed on long-run climate stress, has sharply curtailed exports and damaged processing infrastructure; crucially, as this review shows, the two stressors compound through shared mechanisms rather than acting independently, so resilience depends on interventions that target those shared channels.

Under continued instability, three interventions offer the highest expected return and are robust to an uncertain trajectory: mobile, decentralized animal-health and vaccination services that keep disease and trade barriers in check; feed-security measures, wet-season conservation and residue supplementation that buffer both drought and market disruption; and the rapid re-establishment of reliable, spatially explicit livestock data to target relief and guide recovery. Around these, community-based genetic improvement, protected migration corridors, and value-adding meat processing with traceability can rebuild competitiveness as security allows. Realizing this agenda requires stability and sustained investment, but the scale of the resource and the resilience of its people and animals provide a strong foundation for recovery, provided that decisions are grounded in better data than the sector has had to date.

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AUTHOR CONTRIBUTIONS

H.I.H.H. and T.H.A.M. conceived and designed the review; H.I.H.H. performed the literature search, data extraction, and thematic synthesis; T.H.A.M and I.H. supervised the work, verified the compiled figures, and critically revised the manuscript for important intellectual content; both authors drafted the manuscript and read and approved the final version.

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CONFLICT OF INTEREST

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article, as no new data were created; all data discussed in this review are available in the publicly accessible published studies and official statistics cited in the References.

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