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Cattle population and attributed grazing intensities in Central Equatorial, South Sudan

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The dynamic relationship between humans, cattle and wildlife is currently undergoing significant changes due to population growth, the finite nature of terrestrial resources, and unpredictable atmospheric conditions. While this shift offers benefits for food security, nutrition and livelihoods as animal populations expand, it also presents certain risks. In South Sudan, pastoral practices contribute to varying grazing intensities. This study examines the dynamics of livestock populations and grazing intensities in Central Equatoria State, South Sudan. To assess grazing intensities (GI) in different counties, a Tropical Livestock Unit (TLU)-based methodological approach was used. Grazing intensities were categorized into four levels: Low (0-50,000 TLU), medium (50,001-100,000 TLU), high (100,001-150,000 TLU) and very high (above 150,001 TLU). The results show significant variations ($p < 0.001$) in the number of cattle recorded per county at different grazing intensities. Among the six counties, Terekeka County had "very high" cattle numbers, Juba and Lanya counties recorded high numbers, while Morobo and Kajokeji had low cattle numbers. Schematic mapping also revealed that livestock migrations are influenced by factors such as communal conflicts and the safety of pastoralists, resulting in both normal and abnormal transhumance patterns. Based on the results, it was concluded that the grazing pressure a pasture can sustain depends on the type, number or population index of livestock present.

Key words: Grazing intensities, Tropical Livestock Unit (TLU), livestock migration, Biomass Standard Average (BSA).

INTRODUCTION

The coevolution of humans and domesticated animals has occurred over approximately 11,000 years (Alders et al., 2021). This process of domestication is often depicted as a mutually beneficial relationship between humans and their grounds for domestication, traditional production systems, and the specific agroecological characteristics

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of the local area. They have established a strong link between the sustainability of traditional agricultural systems and the preservation of the local environment. Kauffman et al. (2021), highlight that cattle migrations in South Sudan possess unique characteristics distinguishing them from other global migratory patterns. These migrations rank third globally, with the wildebeest migrations in East Africa and caribou migrations in Alaska holding the first and second positions, respectively. The migratory patterns of nomadic pastoralists from various ethnic backgrounds involve an annual southward movement between January and April, depending on pasture availability. These pastoralists follow three distinct routes that are navigable on foot. Seasonal variations in rainfall, pasture availability, water availability, and animal diseases contribute to fluctuations in pastoral migrations, influencing the creation of grazing intensities. Pastoralists, whose sustenance, social status, and dispute resolution are dependent on their cattle, ascribe significant cultural and economic value to the yearly movement of their livestock, thus intensifying grazing practices (Makarewicz, 2013). Grazing intensity is expressed as the ratio of livestock per unit area multiplied by the length of time they have been present (Rothman-Ostrow et al., 2020). Intensified livestock grazing leads to reduced vegetation density and plant biomass, causing greater disturbance to soil structure (dos Santos et al., 2022; Ji et al., 2020). Animal trampling or compaction alters the soil's physical environment, reducing surface coverage and connectivity, and impacts soil structure and functionality, including soil porosity and water flow (Patiño et al., 2021). These factors make the soil more susceptible to wind and water erosion. Grazing also affects physical processes such as organic matter decomposition, mineralization of soil nutrients, and the habitat of soil fauna, with flow-on effects to plants (Eldridge et al., 2017).

The Ministry of Livestock of South Sudan's national herd census in 2013 estimated the overall livestock population to be over 35 million (Mangara, 2018). This estimate included 11.7 million cattle, 12.4 million goats, and 12.1 million sheep (Catley, 2018). The general health, productivity, and performance of these animals are significantly influenced by grazing intensity and duration. Excessive grazing leads to adverse consequences, including changes in vegetative cover and alterations in species composition. High grazing intensity can result in the complete removal of vegetation, hindering its recovery.

Traditional and nomadic grazing practices, commonly known as transhumance (Motta et al., 2018), are central to determining grazing intensities in South Sudan (Beswick, 1994). This method involves moving cattle herds seasonally between different grazing areas, often following predictable patterns based on the availability of water and forage. These migrations are essential for the survival of livestock and are deeply rooted in local culture, providing a significant source of income for many pastoralist communities. Uniquely, these migrations are associated with "cattle camps"—a system where pastoralists in South Sudan protect their large herds during the night, serving as resting areas for the animals. This study explores the cattle population in South Sudan's pastoral landscapes, examining the distinct categorization of grazing intensities and migration patterns at both interstate and intrastate borders.

METHODOLOGY

Scope of the study

The study was conducted in Central Equatoria State, South Sudan. Geographically, the state is located between longitudes 29° 0' 0" and 32° 0' 0" and latitudes 4° 0' 0" and 6° 0' 0". The total land area covers approximately 43,131 km² (Figure 1).

Data analysis of grazing intensities

The grazing intensities were widely spread across the sampling areas in the target agro-ecological zones of Central Equatoria State in South Sudan. To determine the degree of livestock intensities, a Tropical Livestock Unit (TLU) computed methodological approach was employed. This systematic method involved converting the average cow liveweight (175 kg) to TLUs (Rothman-Ostrow et al., 2020) by dividing the total liveweight by 250 kg. The TLUs were then multiplied primarily by the head population within each county, serving as the reference baseline, as indicated in Equation (Equation 1). The Domestic Animal Diversity Information System (DAD-IS) estimates, which represent the cattle population (>91% equivalent to FAOSTAT estimates), were used for subsequent analysis (FAO, 2020). According to Jahnke (1982), dating back to at least the mid-20th century, the Tropical Livestock Unit (TLU), with a liveweight measurement of 250 kg, has been used as the reference point in low- and middle-income countries (LMICs) for standardizing livestock of various species by biomass.

$$TLU = \left(\frac{175}{250}\right) \times Population \quad (1)$$

Categorization of grazing intensities

To utilize the TLU, the grazing intensities were determined using a Likert scale ranking model ranging from very high, high, medium, and low. The GI cattle population categorization index is shown in Table 1.

Migration pattern classification

In this study, the animal migration patterns are presented into four classifications as defined:

a) High intensity normal migration pattern: Livestock in this pattern migrate in a predictable, large-scale manner. Usually happening yearly, it follows set paths and time depending on customs and seasonal fluctuations.
b) High intensity normal return migration pattern: This pattern describes the predictable, large-scale migration of cattle back to their natural habitats.
c) Medium intensity abnormal migration pattern: This trend deviates from the conventional, regular migration routes and dates

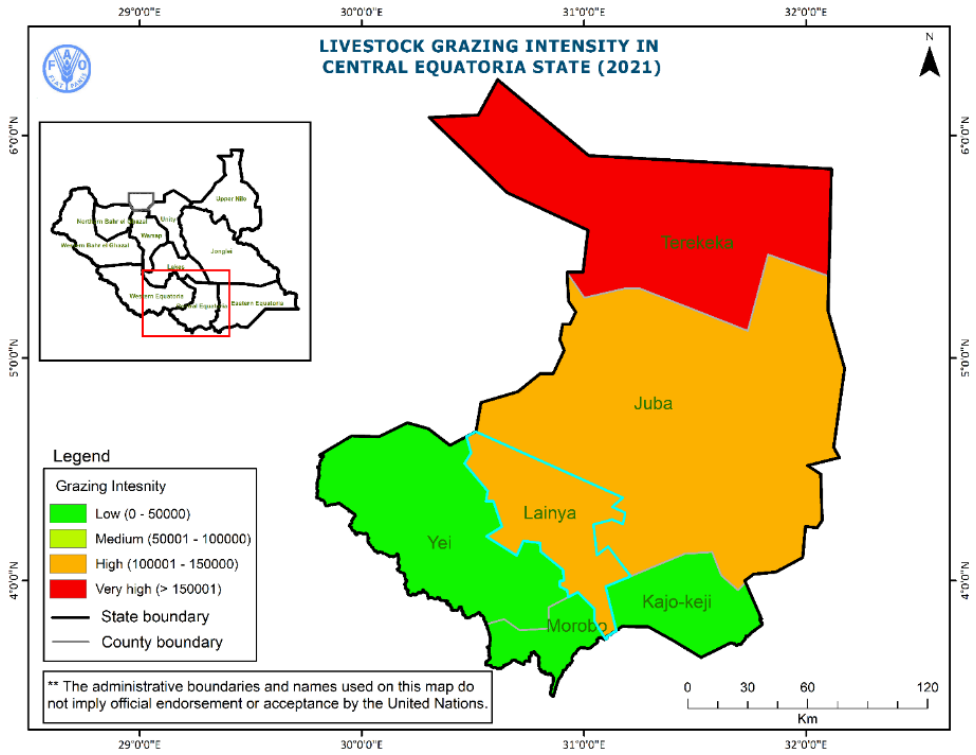

Figure 1. Categories of grazing intensities in Central Equatoria, South Sudan

Table 1. Categorization of grazing intensities.

Cattle population	Likert scale/grazing intensity
0-50.000	Low
50.001-100.000	Medium
100.001-150.000	High
Above 150.001	Very high

by involving a moderate volume of cattle movement. Usually, it is a reaction to unique environmental conditions or sociopolitical elements.
d) Low intensity abnormal migration pattern: This pattern often results from specific and localised problems; this pattern consists of a limited scale of cattle movement deviating from the usual, predictable migration paths and dates.

Vegetation indices and migration patterns

Google Earth Engine (GEE) and the Application Programming Interface (API) were used to obtain satellite imagery of the study area over a period between July 2022 and February 2023. Captured and processed images were of sufficient spatial resolution with a frequency capturing changes in vegetation cover and other factors that may affect clarity, where two approaches were used:

a) Preprocess the imagery: Preprocess the satellite imagery to remove clouds, shadows, and other sources of noise that may affect the accuracy of the analysis. This involved using filters or algorithms to remove unwanted pixels or to enhance features of interest.
b) Estimate vegetation cover: Use of satellite imagery to estimate vegetation cover over time. This involved calculating vegetation indices through the normalized difference vegetation index (NDVI) or the enhanced vegetation index (EVI).

The Normalized Difference Vegetation Index (NDVI) technique was employed, a robust method for examining vegetation dynamics over time using satellite imagery (Iverson et al., 2023). This technique provided a comprehensive understanding of how cattle migration affects grazing intensities by analyzing NDVI data across different seasons (Razipoor, 2019). Areas with verdant vegetation were delineated and pinpointed, indicating optimal grazing zones, while areas with diminished NDVI values suggested potential overgrazing or degraded vegetation cover. Cattle migration patterns were superimposed onto NDVI maps to correlate their movements with changes in vegetation. This integrated approach facilitated the evaluation of grazing intensities in specific regions and helped identify areas where livestock may be exerting pressure on vegetation resources. The findings are represented as maps in this

Table 2. Grazing intensity.

Number in cattle categorization	Grazing intensity	County
0-50.000	Low	Morobo, Kajokeji
50.001-100.000	Medium	Yei
100.001-150.000	High	Juba, Lainya
Above 150.001	Very high	Terekeka

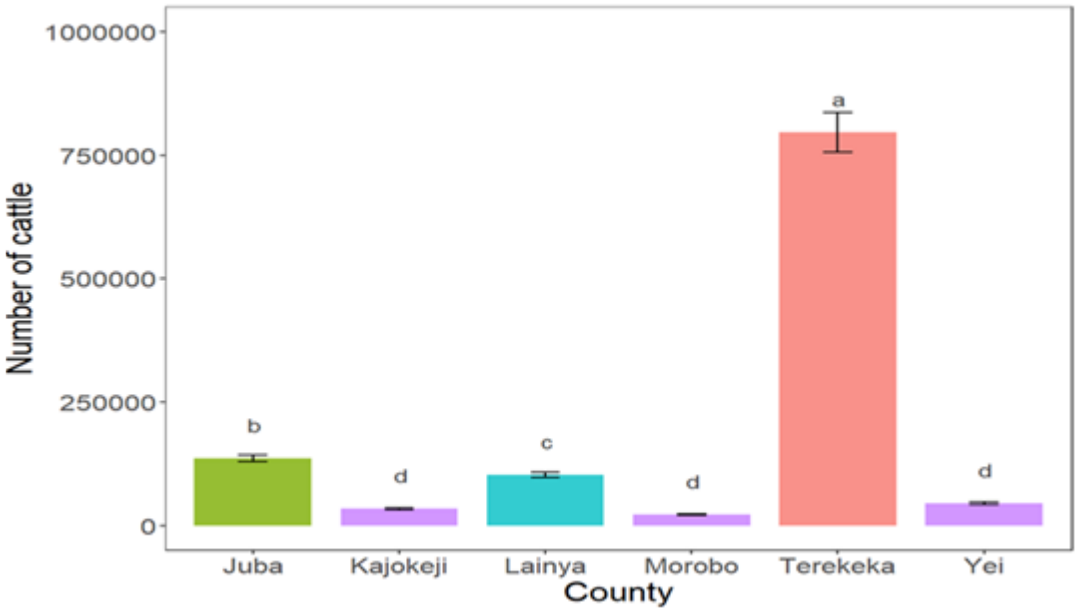

Figure 2. Number of cattle recorded per county. Significance: P≤0.001***.

study, showing schematic livestock migration patterns and landscape classifications.

RESULTS AND DISCUSSION

Grazing intensities in central equatorial state

The categorization of cattle determined the grazing intensity potential as low, medium, high, and very high based on the cattle category clusters (Table 2). These categories ranged from 0 to 50,000 (low), 50,001 to 100,000 (medium), 100,001 to 150,000 (high), and above 150,001 (very high). Results in Table 2 show that different counties in CES had varying intensity potentials according to the projected cattle numbers. Specifically, Terekeka County exhibited "very high" cattle numbers, Juba and Lanya counties recorded high numbers, while Morobo and Kajokeji had low cluster cattle numbers.

Results in Figure 2 show significant variations ($p<0.001$) in the number of cattle recorded per county across different observed grazing intensities. Terekeka recorded the highest number of cattle (796,634), followed by Juba with 136,566 cattle (Figure 2). This disparity could be attributed to factors such as the dominance of pastoral activity in Terekeka, water availability, the extent of grassland, and the climatic conditions of the area.

Grazing intensity and the TLU

To ascertain the grazing intensity of cattle on pasture in CES, Table 3 presents TLUs for a five-year period (2015 to 2020). According to Fetzel et al. (2017), TLU is a measurement used to estimate the grazing intensity of cattle on a specific pasture. It is based on the principle that different types of livestock have varying grazing requirements; thus, the amount of grazing pressure a pasture can sustain depends on the type and number of livestock presents (Table 3).

To distinguish the annual variations in grazing intensity (GI), the total number of cattle heads was divided by the Biomass Standard Average (BSA) and the live weight (Equation 1). The results indicate a steady increase in TLUs from 2015 to 2020, with the lowest TLUs recorded in 2015 (735.893.2) and the highest in 2020 (832.516.3).

Table 3. Cattle calculated by standard average of 175 Kg and TLUs in Central Equatorial State.

Central Equatorial State (CES)	Year	Head	Biomass by standard average (head × 175 kg)	TLUs
CES	2015	1051276	183.973.300	735893.2
CES	2016	1082815	189.492.625	757.970.5
CES	2017	1115299	195.177.325	780.709.3
CES	2018	1148758	201.032.650	804.130.6
CES	2019	1171733	205.053.275	820.213.1
CES	2020	1189309	208.129.075	832.516.3

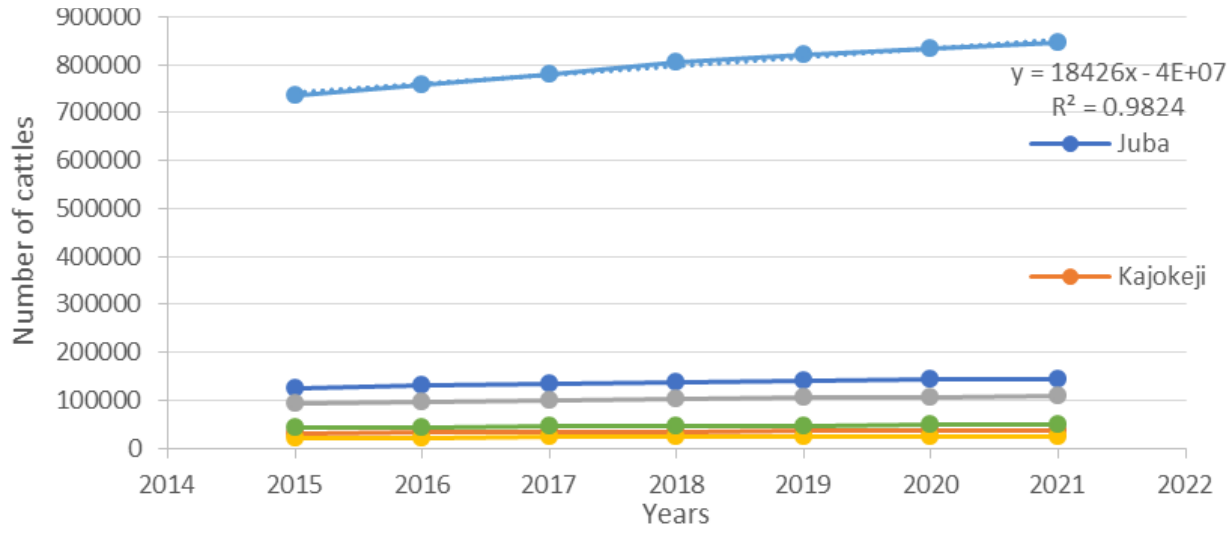

Figure 3. Number of cattle recorded per county per year.

According to Table 3, the number of cattle heads increased annually in CES, leading to a rise in TLUs over the years. Higher TLUs corresponded with increasing GI, which influences both normal and abnormal cattle movements.

Recorded annual cattle trend in central equatorial

Figure 3 shows that the number of cattle in each county varied from 2015 to 2021. Terekeka had the highest annual cumulative trend index across all years, with an equation index intercept of y=1846x−4E+07y = 1846x - 4E+07y=1846x−4E+07 and R2=0.9824R^2 = 0.9824R2=0.9824, indicating the highest percentage increase in cattle numbers. Other counties displayed increasing trends with observable increments over the years (Figure 3). In 2021, the most noticeable cumulative increases were observed, with Terekeka recording the highest and Morobo and Kajokeji the lowest. This increase in cattle numbers is likely attributable to the farming activities and cultural values associated with livestock in South Sudanese communities.

According to Idris (2018), the increase in cattle and livestock in South Sudan can be attributed to several factors. Cattle play a significant role in South Sudanese culture and economy, serving as a form of currency and a source of food and wealth. South Sudan's predominantly agricultural economy relies heavily on cattle farming (Museli, 2017). The rising demand for beef and dairy products has led to an increase in cattle numbers. Additionally, recent improvements in security in some regions (Rolandsen, 2019) have enhanced mobility and access to grazing areas, enabling farmers to expand their herds (Luizza, 2017). Traditional cultural practices, such as cattle raids and dowry payments, also contribute to the increase in cattle numbers. However, despite the growth in cattle populations, South Sudan faces significant challenges, including food insecurity, poverty, and conflict, which impact the livelihoods of those who depend on cattle farming for their income and sustenance.

Livestock migration patterns in central equatorial state

Figure 4 displays the land cover classifications, grazing

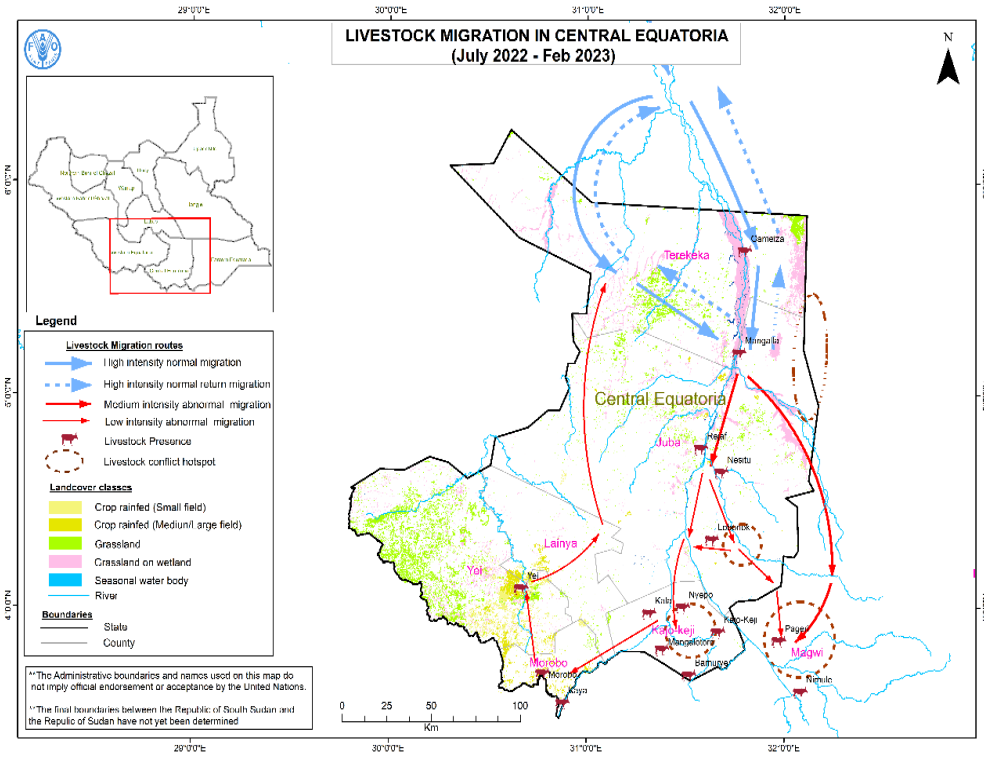

Figure 4. Livestock migration in Central Equatorial State (July 2022-Feb 2023).

intensities, and migration patterns for cattle in Central Equatoria State (CES). Due to the nomadic nature of pastoralists, cattle movements span across county boundaries within CES, including Terekeka, Yei, Juba, Magwi, Kajo-Keji, Molobo, and Lainya. The map reveals both normal and abnormal migration patterns, particularly in the northwestern parts of CES. High-intensity normal migration was predominantly observed in the northern part of CES, specifically in Terekeka County along Gameiza and Mangalla. This migration is notable for crossing the inter-state boundary, with livestock moving into Central Equatoria and returning to Jonglei State. The temporal results indicated in Figure 4 show that grazing intensities on pasture were significantly influenced by climate seasonality, water availability, and the cattle migration patterns. These findings provide valuable insights into the effective management of grazing resources and the sustainable use of grasslands in Central Equatoria State.

Figure 4 also shows the low and medium intensity categories. The primary difference between these categories is their spatial distribution within CES. Moderate and low migrations were found to be abnormal, largely due to the exacerbation of livestock conflict hotspots in Kajokeji and Magwi. This situation forced pastoralists to seek new pastures towards the western part of CES, settling along Malobo and Yei as they moved towards the northern parts of Lainya and Terekeka Counties. Overall, conflicts can have complex and far-reaching effects on grazing intensities in South Sudan, with both positive and negative impacts depending on specific circumstances. These findings align with Mohamed's (2022) work on how conflict impacts the delicate semi-arid grasslands of pastoral landscapes in Sudan. Ellsberg et al. (2020) also reported that conflicts can significantly affect grazing intensities in South Sudan.

The country's largely pastoralist population relies heavily on livestock for their livelihood. Conflicts, such as intercommunal violence or civil unrest, can disrupt traditional grazing patterns and cause significant changes in grazing intensity and distribution. During conflicts, people may be displaced from their homes, and their livestock may be killed, stolen, or lost, leading to reduced grazing pressure in some areas as people move away from conflict zones or have fewer animals to graze. Conversely, in other areas, conflict may increase grazing pressure as people concentrate their herds in more secure locations or move to new areas in search of pasture.

According to Figure 5, land cover classifications have directly or indirectly impacted the migration behavior of livestock. The existing classes include crop rain-fed small fields, crop rain-fed medium/large fields, grasslands, grassland on wetland, and seasonal rivers. The northern region of CES, dominated by grasslands and the

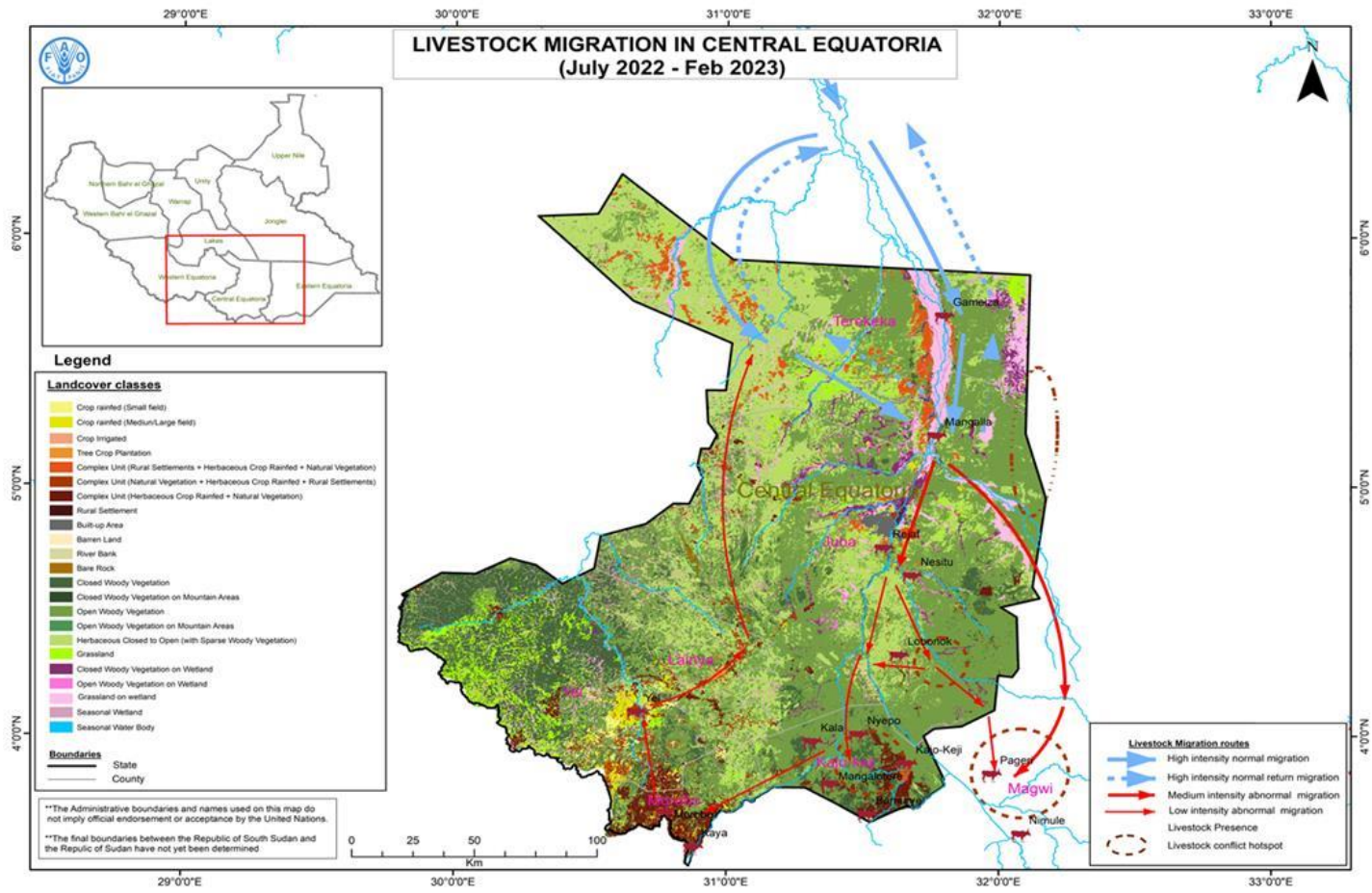

Figure 5. Land cover classes and livestock migration patterns.

permanent River Nile, attracted higher intensity levels compared to other regions. In contrast, the southwestern counties, with farming activities and large forested areas in Yei County, limited livestock migrations and pastoral activities, were serving as a transit path to the dominant northern pastoral counties. Land covers classifications and livestock migration routes in Central Equatorial State, South Sudan.

Figure 5 shows the land cover classes along the pastoral transhumance livestock system in CES, South Sudan. The spatial schematic analysis reveals distinct findings based on migration patterns and vegetation types. The dominant land cover classes are open woody vegetation, grasslands, and herbaceous areas (both closed and open). The built-up environment is minimal, with few rural settlements.

Migration patterns and intensities are classified as either abnormal or normal. High-intensity normal and return migrations are predominant in the northern parts of CES, particularly in Terekeka along the Gameiza and Mangalla landscapes. These areas exhibit high intensity due to the abundance of water sources, including the Nile River, wetlands, and open woodland vegetation.

Medium-intensity abnormal migrations are observed towards the eastern parts of Nesitu and along Rejaf landscapes. Low-intensity abnormal migrations are noted along Lobonok landscapes, attributed to livestock conflict zones exacerbated by cattle rustling, ethnic grazing conflicts, and general insecurity. This observation is supported by Yesuph and Dagnew (2019), who described similar spatiotemporal dynamics along the Blue Nile Basin.

Conclusion

The results have shown varying grazing intensity categorizations and livestock migration behavioral patterns in CES across different counties. The migratory patterns of nomadic pastoralists depend on pasture abundance. The study indicates that transhumance is a predominant practice in the pastoral system of CES. Livestock grazing intensity on grasslands is categorized into low, medium, high, and very high, depending on the number of cattle and migration patterns—normal or abnormal. Key factors influencing these patterns include

pasture availability, security, conflict hotspots, climate seasonality, and water availability. Consequently, these factors impact the population growth index of livestock in Central Equatoria State (CES). Over the past decade, the projected livestock growth index has increased in the target areas of CES.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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