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From rural to urban: Exploring livestock farming practices in urbanizing landscapes

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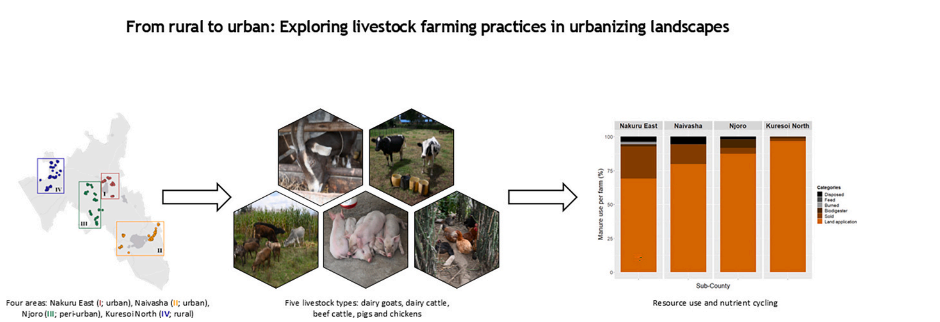
HIGHLIGHTS

- Urbanization even effects relatively remote rural areas.
- Shift towards intensive, market-oriented farming across all areas.
- Studying all livestock species shows important herd size and diversity variations.
- High stocking rates maintained along urbanization gradient.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Urbanization in Kenya continues to accelerate, reshaping the agricultural landscape and impacting livestock farming practices.
OBJECTIVE: This study investigated the spatial variation of livestock farming systems across urban, peri-urban, and rural areas in Nakuru County to assess the impact of urbanization on resource use, nutrient cycling, and livestock diversification.
METHODS: A multi-stage cluster sampling method was used to interview 241 households selected from four sub-counties: Nakuru East (urban), Naivasha (urban), Njoro (peri-urban), and Kuresoi North (rural). In each sub-county, three wards were selected, with four selected roads per ward. A structured questionnaire was administered to collect data on farm size, herd size and diversity, feeding practices, manure management, and market access.
RESULTS: The total herd size, including all animal species present on the farm, was lower in the urban area of Nakuru East than in all other areas ($P < 0.001$). However, the numbers of individual species (i.e., dairy cattle, dairy goats, and chickens) per farm did not differ among areas and were not significantly correlated to land size. On average, farmers kept 4.6 dairy cattle, 6.2 dairy goats, and 49.1 chickens if they had those species. In the urban areas of Nakuru East, land scarcity led to limited space for forage production. The other areas prioritized land use for crop production over that for forage production for their livestock. Our findings indicate high stocking rates across all areas: urban areas averaged 41.8 TLU/ha and peri-urban and rural areas averaged over 6 TLU/ha. The high stocking rates and low forage production explain the overall dependency on feed purchases.

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Agricultural supply stores were present in all areas, providing opportunities for feed and other input purchases. Peri-urban and rural farms relied more on compound feeds, while urban farms purchased specific energy- and protein-rich ingredients for their livestock diets. Due to the high dependency on feed purchases and small land size, farms face nutrient accumulation in the form of manure, creating risks of environmental hazards. Overall, our research reveals that urbanization has created a shift towards more intensive and market-oriented farming across all areas.

SIGNIFICANCE: Understanding the interaction between urbanization and livestock farming practices is crucial for developing sustainable agricultural production and marketing strategies that can accommodate the changing landscape of urbanizing areas.

1. Introduction

Urbanization in Kenya has seen significant growth over recent decades, with urban population increasing from 10 % in 1970 to 29 % by 2020 (UN-Habitat, 2023; World Bank, 2024). This growth is driven by factors such as population growth and rural-urban migration due to economic opportunities in urban regions. The demand for animal source products rises as urban populations grow, economic status improves, and dietary preferences shift (Delgado, 2005; Oosting et al., 2014; Tacoli and Agergaard, 2017; Worku et al., 2017). While the majority of food production occurs in rural areas, agricultural products consumed in urban centers may originate from urban and peri-urban agriculture as well (Omondi et al., 2017). Urban livestock farming mainly produces perishable goods with relatively high economic margins, targeting urban consumers (Cofie et al., 2003; Moustier and Danso, 2006). On the other hand, urbanization creates challenges for urban and peri-urban farming by putting pressure on land availability and other resources (Kuusaana and Eledi, 2015).

Intensification of the livestock sector in urban areas, characterized by increased animal source product outputs per hectare, is accompanied by the use of high-quality external feed sources such as concentrate feed (e.g., maize, wheat, soy), machinery and other equipment (Delgado, 2005). High dependency on external feed sources can disrupt nutrient cycles, depleting resources (e.g., nitrogen, phosphorus, potassium) in areas where the feed is produced and leading to accumulation of these resources in areas where livestock is raised (van Selm et al., 2023). In contrast, rural areas are often characterized by extensive forms of agriculture, with integrated crop-livestock systems that depend less on external sourced feed. These farms produce crops for food, use crop residues to feed animals, and apply animal manure to fertilize the land, consequently creating an active circular food system (Oosting et al., 2022).

While previous studies have examined the effects of location on land use (Willkomm et al., 2021), crop production (Boudet et al., 2020; Iheke and Ukandu, 2015), poultry farming (Wilson et al., 2021), and dairy farming (Migose et al., 2018; van der Lee et al., 2020), there remains a gap in understanding how urbanization affects livestock farming systems beyond a single-species approach. This study aims to address this gap by investigating how urbanization influences resource use, nutrient cycling, and livestock diversification within livestock farming systems across urban, peri-urban, and rural areas, using Nakuru County as a case study. By analyzing a broad spectrum of livestock species, including dairy and beef cattle, dairy goats, pigs, and poultry, this study aims to provide a detailed and comprehensive understanding of the spatial variation shaping livestock farming systems along an urbanization gradient.

By formulating explicit hypotheses, we establish a clear theoretical framework to examine how urbanization affects land use, stocking density, farm specialization, trading livestock products, and manure management in livestock farming systems. We hypothesize that in urban areas, the high demand for land results in small farm plots and elevated land prices (Jiang et al., 2013; Migose et al., 2018). While the herd size of producing animals may be comparable between urban and rural regions, the reduced land size in urban areas tends to lead to higher stocking rates (Lobago et al., 2006; Migose et al., 2018). We further hypothesize that farm specialization is more prevalent in urban and peri-urban areas, while rural farms maintain livestock species diversity for greater resilience (Roessler et al., 2016). Urbanization is anticipated to facilitate the concentration of monogastric farming systems, such as those of pigs and poultry, in urban and peri-urban areas (Steinfeld et al., 2006), while ruminants, such as cows, sheep, and goats, will predominantly be in rural areas due to their reliance on land for grazing and fodder resources. Access to external feed sources is expected to be similar across areas due to the presence of agricultural supply stores (Migose et al., 2018; van der Lee et al., 2020). However, rural farmers will predominantly depend on natural pasture and crop residues (Gebremedhin et al., 2014), while urban farmers will typically purchase fodder and commercial feeds from local markets (Tegegne, 2004). In all areas, a high proportion of animal source products is expected to enter the informal market due to better prices offered (Kanire et al., 2024). We also hypothesize that livestock manure will accumulate in urban areas due to feed imports and limited land for manure application, which could potentially lead to public health and environmental hazards (Ström et al., 2018). We expect that surplus manure is typically disposed of through methods such as dumping and selling, though it may be converted into cakes for use as kitchen fuel (Lupindu et al., 2012; Ström et al., 2018; Tegegne, 2004).

Understanding the interaction between urbanization and livestock farming practices is crucial for developing sustainable agricultural production and marketing strategies that can accommodate the changing landscape of urbanizing areas. This study offers a novel perspective by including multiple livestock species, providing a more holistic view of livestock production along an urbanization gradient. We investigate how the intensification of livestock farming and reliance on certain resources can potentially affect nutrient cycling in different farming contexts. This provides a comprehensive analysis of the interactions between urbanization and livestock production. The findings will be instrumental in informing policymakers and stakeholders on options for promoting sustainable development in the agricultural sector, helping to balance the demands of urbanization with the need for environmentally sound farming systems.

2. Material and methods

2.1. Study area

The study was conducted in Nakuru County, one of the 47 counties of Kenya. The county is located in the highlands of Kenya with an area of approximately 7500 km^2 (Latitude: 0.28° to 1.05° S, Longitude: 35.73° to 36.55° E) and a wide variation in altitude (1400 to 2970 m.a.s.l.). Nakuru County has nearly 2.3 million inhabitants, with around 38 % living in urban centers (CGoN, 2018; KNBS, 2019a). The region is characterized by fertile soils, favorable climate, and relatively easy access to water sources, creating a good environment for agricultural production and livestock keeping. Variations in annual rainfall are observed across distinct agro-ecological conditions, with an average annual precipitation exceeding 1400 mm in highland regions and approximately 500 mm in semi-arid regions.

Dairy cattle farming is the main economic livestock activity, but other livestock such as beef cattle, goats, poultry, and pigs are also reared in various parts of the county, contributing to both subsistence and commercial agriculture. The study area includes Nakuru Town and Naivasha, two major urban centers experiencing high population growth (Mubea and Menz, 2012). Nakuru was designated a city in 2021 under Kenyan constitutional provisions, becoming the fourth largest city in Kenya. Naivasha, a trade and tourism hub town due to its strategic location between Nairobi and Nakuru city, is also characterized by large-scale horticulture and floriculture farms.

A field survey was conducted in four sub-counties of Nakuru County: Nakuru East *(area I)*, Naivasha *(area II)*, Njoro *(area III)* and Kuresoi North *(area IV;* Fig. 1). Sub-county selection was done purposively to ensure a diverse rate of urbanization, a gradient to the administrative centre and a varied representation of livestock species (KNBS, 2019a, 2019b). Local experts, such as university staff and County Government officials, were consulted during the selection process. Nakuru East covers part of the well-established city centre of Nakuru and has a population of 193,926, classifying it as an urban area. Naivasha, located 70 km from Nakuru's administrative centre, is a fast-growing sub-county with 355,383 inhabitants and was therefore also classified as urban. Njoro, located 20 km from the administrative centre, has a population of 238,773 and was classified as peri-urban. Kuresoi North, located 55 km from the administrative center, has a population of 175,074 and was classified as rural. Demographic details of the four sub-counties are presented in the supplementary material.

2.2. Sampling method

The selection of households was done through multi-stage cluster sampling, following the hierarchical administrative structure of the study sites (Nyariki, 2009). In the first stage cluster sampling, three wards were purposively selected from each of the four sub-counties (i.e., area I-IV) with guidance from local livestock extension officers in the sub-county. To minimize potential sampling bias introduced by reliance on extension officers, selection criteria were explicitly defined to ensure objectivity. The criteria included the presence of our target livestock species (i.e., dairy cattle, dairy goats, beef cattle, pigs, and chickens) and varying distances from the administrative centre of the sub-county. Additionally, random selection was applied in subsequent stages to further reduce bias.

In the second stage, four roads/areas per ward were selected with the assistance of local livestock extension officers in the ward. In the third stage, systematic sampling was used to select an average of five households per roads/area, achieved by visiting every fifth household (Forthofer et al., 2007). Households were included if the farmer or farm representative confirmed that at least one of the target livestock species was present. If none of the target livestock species were present, the survey moved to the next household. In total 18–23 households were visited per ward, leading to a total of 56 households in Nakuru East, 61 farms in Naivasha, 55 farms in Njoro and 69 farms in Kuresoi North.

2.3. Data collection

A field survey was conducted from July to September 2021 with the help of seven trained local enumerators. The structured questionnaire was adapted from Wilkes et al. (2019) and modifications to align with the objectives of this study. The questionnaire was used to collect qualitative and quantitative data about the farming practices from the previous 12 months (see supplementary material for questionnaire). The questionnaire was pre-tested on one farm per target livestock species (i.e., dairy cattle, dairy goat, pig and chicken) to ensure clarity of phrasing, completeness and applicability. Feedback from pre-testing resulted in several refinements, including the rewording of questions for improved clarity, the addition of specific livestock breeds, forage and fodder types, and concentrate types relevant to the local context. For example, dual-purpose chickens were categorized as indigenous and improved indigenous chicken to reduce respondent confusion. These changes enhanced the reliability of data collection by ensuring that the questionnaire captured locally relevant information accurately and consistently.

On arrival at each farm, enumerators explained the purpose of the study and obtained written consent for participation, indicating their agreement for the use of collected data in the study. A farm tour was conducted prior to the interview to facilitate visual observations. The farm tour provided background information that enabled enumerators to identify inconsistencies or potential inaccuracies in the interviewee's responses. The questionnaire covered household information such as the respondent's relation to the farm, gender, location, and farm size. Livestock-related information, including species, breeds, and herd composition was also collected. Additionally, data regarding animal feed sources, including forage (i.e., plant material such as grass that livestock graze on directly), fodder (i.e., plant material that is harvested and provided to livestock such as hay or silage), vegetable (residues), concentrate feed, and water sources were collected. Landless farms did neither produce forage, fodder nor crops. Information on manure management (i.e., collection, storage, and utilization) and traded

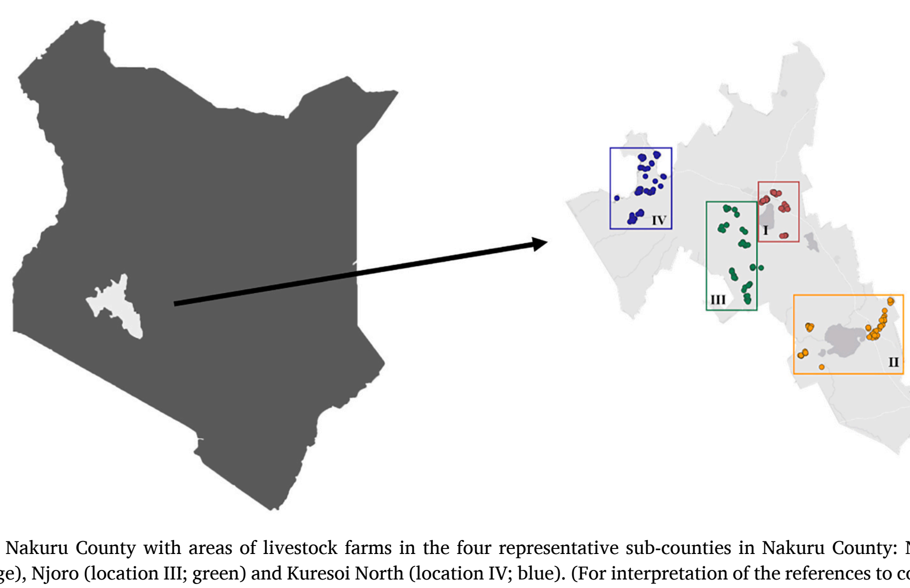

Fig. 1. Map of Kenya and Nakuru County with areas of livestock farms in the four representative sub-counties in Nakuru County: Nakuru East (location I; red), Naivasha (location II; orange), Njoro (location III; green) and Kuresoi North (location IV; blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

livestock products was collected as well. Immediately after administering the questionnaire, the enumerator assessed the reliability of the interview by checking for consistency in answers and straightforward responses that confirms interviewee's knowledge and experience on the topic. Later the same day, the first author of this paper reviewed the quality of the interview by further evaluating the consistency of the information and cross-verifying with the enumerator when necessary. If the reliability or quality was insufficient, the interview was excluded from the dataset.

2.4. Data analyses

Numerical variables were converted to universal standard units: 2.5 acres was 1 ha (ha), and an animal of 250 kg was 1 tropical livestock unit (TLU) (Castellanos-Navarrete et al., 2015). Land was categorized in cropland, fodder land, grassland, and land for buildings and non-farm activities. The distance to the nearest major town from each farm was calculated using road distance measurements based on the GPS coordinates of both the farm and the town (Nakuru East: Nakuru, Naivasha: Naivasha, Njoro: Njoro, Kuresoi North: Molo). Animal feed was categorized into the following groups: cultivated grass (e.g., *Pennisetum purpureum*: Napier grass, *Chloris Gayana*: Rhodes grass), scavenged feed (e.g., road side grazing), fodder legumes (e.g., *Medicago sativa*: lucerne, *Desmodium intortum*: desmodium), maize silage, vegetable residues (e.g., cabbage, beans), cereal residues (e.g., maize stovers, wheat straw), other forages, waste (e.g., food waste), "only concentrate", compound feed (e.g., dairy meal, pig finisher meal), energy-rich concentrate feed (e.g., maize germ, wheat bran), protein-rich concentrate feed (e.g., soybean meal, cottonseed cake), supplement (e.g., minerals, vitamins), manure (e.g., chicken manure) and "no concentrate".

Statistical analysis was conducted using RStudio version 2023.12.0. Variables were tested for normal distribution using the Shapiro-Wilk test. Due to the non-normal distribution of the data, non-parametric tests were chosen for subsequent analyses to ensure robustness. Kendall rank correlation test was used to test correlations between distance to town (km), farm size (ha) and herd size (TLU). This test was selected because it is robust to tied ranks and performs well with smaller datasets, making it particularly suitable for the context of this study. Differences between areas were examined using the Kruskal-Wallis test, a rank-based non-parametric test that accounts for the non-normal distribution of data and is appropriate for comparing multiple independent groups. To ensure valid comparisons, we considered the assumptions of the Kruskal-Wallis test, such as the independence of samples. Following significant results in the Kruskal-Wallis test, post-hoc pairwise comparisons were conducted using Dunn's test with Bonferroni correction to control for Type I error resulting from multiple comparisons. This method provides a rigorous approach to identifying specific group differences while maintaining statistical validity.

3. Results

3.1. Farm size in urban, peri-urban, and rural areas

Average total farm size was lower in the urban area of Nakuru East than in all other areas ($P < 0.001$), with 18 farms only having a small piece of land for buildings (i.e., landless farms; Table 1; Fig. S1 + S2). Despite being in an urban area, Naivasha had on average the largest farm size, with some farms encompassing many hectares, while still accommodating landless farms (5 farms). Farms in Naivasha, Njoro and Kuresoi North allocated most of their land to crop cultivation. Farms in the rural area of Kuresoi North had significantly more grassland than all other areas ($P < 0.001$). Herd size (in TLU) was lower in Nakuru East than in the other areas ($P \leq 0.03$; Fig. S3). Nakuru East showed higher stocking rates and lower livestock diversity than peri-urban and rural areas (both, $P < 0.001$; Fig. S4 + S5). Positive correlations were found between farm size (ha) and herd size ($r = 0.32$); between distance to town (km) and farm size ($r = 0.35$); between distance to town and herd size ($r = 0.17$); and a negative correlation between distance to town and stocking rate ($r = -0.20$).

Table 1
Farm size based on land size and tropical livestock units (TLU) in urban, peri-urban, and rural areas in Nakuru County (mean ± SD).

Item	Urban Nakuru East ($n = 56$)	Urban Naivasha ($n = 61$)	Peri-urban Njoro ($n = 55$)	Rural Kuresoi North ($n = 69$)
Farm size (ha)	0.4 ± 0.61 ^{a}	3.4 ± 10.37 ^{c}	1.8 ± 1.72 SD ^{bc}	2.5 ± 4.29 ^{b}
Cropland (ha)	0.1 ± 0.18 ^{a}	2.2 ± 9.25 ^{c}	1.0 ± 0.96 SD ^{b}	1.5 ± 3.63 ^{b}
Fodder land (ha)	0.1 ± 0.35 ^{a}	0.4 ± 0.84 ^{a}	0.4 ± 0.68 SD ^{b}	0.3 ± 0.54 ^{b}
Grassland (ha)	0.1 ± 0.28 ^{a}	0.2 ± 0.59 ^{a}	0.2 ± 0.57 SD ^{a}	0.4 ± 0.67 ^{b}
No. of landless farms	18	5	0	0
Herd size (TLU)	5.0 ± 5.06 ^{a}	9.2 ± 8.30 ^{b}	8.4 ± 7.73 ^{b}	8.7 ± 6.58 ^{b}
Stocking rate (TLU/ha)	66.4 ± 190.92 ^{a}	19.3 ± 30.55 ^{a}	9.6 ± 20.26 ^{b}	6.3 ± 5.57 ^{b}
Livestock diversity (# of species/farm)	2.3 ± 1.35 ^{a}	2.8 ± 1.38 ^{ac}	3.7 ± 1.30 ^{b}	3.1 ± 1.00 ^{bc}

[a,b,c] Within a row, means with different superscripts differ ($P < 0.05$).

3.2. Herd composition in urban, peri-urban, and rural areas

Chicken was the predominantly kept animal species in all areas, with a large variation in number of birds kept (Table 2). No significant difference was found in the number of chickens (absolute and TLU) kept by chicken farmers across different areas. The majority of the poultry farmers kept indigenous ("*Kienyeji*") or improved indigenous chicken, while only 4 farmers kept pure broiler lines (e.g., Cobb, Ross) and 6 farmers kept pure layer lines (e.g., ISA brown, Highline). The indigenous and improved indigenous chicken were kept as dual-purpose chicken (i.e., for eggs and meat). In Nakuru East, 30 % of all farms specialized in chicken farming, with flock sizes ranging from 5 to 1600 birds, while in Naivasha, 13 % of farmers (PoF) were dedicated to chicken farming, with flock sizes varying from 6 to 480 birds. Njoro and Kuresoi North only had 3 and 1 specialized chicken farms, respectively. Of the total 29 specialized chicken farms in Nakuru County, 34 % of the farms were landless.

A larger percentage of farmers in the peri-urban and rural areas kept dairy cattle (80 and 96 PoF, resp.) than farmers in the urban area of Nakuru East (36 PoF). No significant differences were found in the number of dairy cattle (absolute and TLU) kept by dairy cattle farmers across different areas. The majority of the farmers kept Holstein-Friesians (68 PoF), followed by Ayrshire (31 PoF), a crossbreed of Holstein-Friesians and other breeds (6 PoF), and a few farmers kept Jersey, Guernsey, Sahiwal or Boran. Multiple breeds were kept by 29 PoF. A few farmers specialized in dairy cattle (14 out of 241), but most farmers kept dairy cattle in combination with chicken. The combination of dairy cattle and chicken was seen in 20 %, 40 %, 67 % and 49 % of the farms visited in Nakuru East, Naivasha, Njoro and Kuresoi North, respectively.

Dairy goats were kept in all areas, with limited differences in PoF keeping goats, or in the number of goats (absolute and TLU) kept by dairy goat farmers across different areas. Toggenburg and Alpine were the dominant goat breeds observed (83 PoF). Only 5 out of 241 farms in Nakuru County were specialized goat farms, of which 3 farms were landless.

Pigs were mainly kept in urban and peri-urban areas, rarely in the rural area. Pig farmers in Naivasha had a significant higher number of pigs (absolute and TLU) on their farm than pig farmers in Nakuru East

Table 2
Types and numbers of livestock on farms in urban, peri-urban, and rural areas in Nakuru County.

	% of farms				Number of livestock (mean ± SD)*				TLU (mean ± SD)*			
Livestock species	Urban Nakuru East	Urban Naivasha	Peri-urban Njoro	Rural Kuresoi North	Urban Nakuru East	Urban Naivasha	Peri-urban Njoro	Rural Kuresoi North	Urban Nakuru East	Urban Naivasha	Peri-urban Njoro	Rural Kuresoi North
Dairy cattle	36 %	67 %	80 %	96 %	4.4 ± 3.47	5.4 ± 4.28	4.3 ± 4.99	4.5 ± 3.32	6.6 ± 4.48	8.2 ± 6.55	6.5 ± 7.16	6.9 ± 4.81
Dairy goats	20 %	20 %	31 %	20 %	4.2 ± 3.28	3.4 ± 3.42	13.6 ± 40.89	3.4 ± 1.86	0.7 ± 0.68	0.5 ± 0.60	2.3 ± 6.79	0.7 ± 0.39
Beef cattle	4 %	3 %	0 %	0 %	4.0 ± 0	6.0 ± 4.24	0	0	7.6 ± 2.83	14.5 ± 13.15	0	0
Pigs	29 %	11 %	27 %	4 %	15.9 ± 12.48 ^{a}	38.6 ± 19.54 ^{b}	14.2 ± 12.11 ^{a}	26.3 ± 33.72 ^{ab}	3.9 ± 3.20 ^{a}	10.0 ± 3.21 ^{b}	3.9 ± 3.28 ^{a}	6.2 ± 8.17 ^{ab}
Chickens	73 %	84 %	95 %	93 %	85.3 ± 253.92	46.4 ± 79.07	35.4 ± 49.27	29.4 ± 22.99	0.6 ± 1.72	0.3 ± 0.63	0.2 ± 0.32	0.2 ± 0.18

^{a,b}Within a row, means with different superscripts differ ($P < 0.05$).
* Number of livestock (absolute and TLU) is based on the average for farms keeping the specific species.

and Njoro ($P \leq 0.01$). The majority of the farmers kept Large White, or a crossbreed of Large White with Landrace or Hampshire (71 PoF). Only 5 out of 241 farms in Nakuru County were specialized pig farms, of which 1 farm was landless.

Beef cattle were rarely observed in Nakuru County, with only two farms each in Nakuru East and Naivasha.

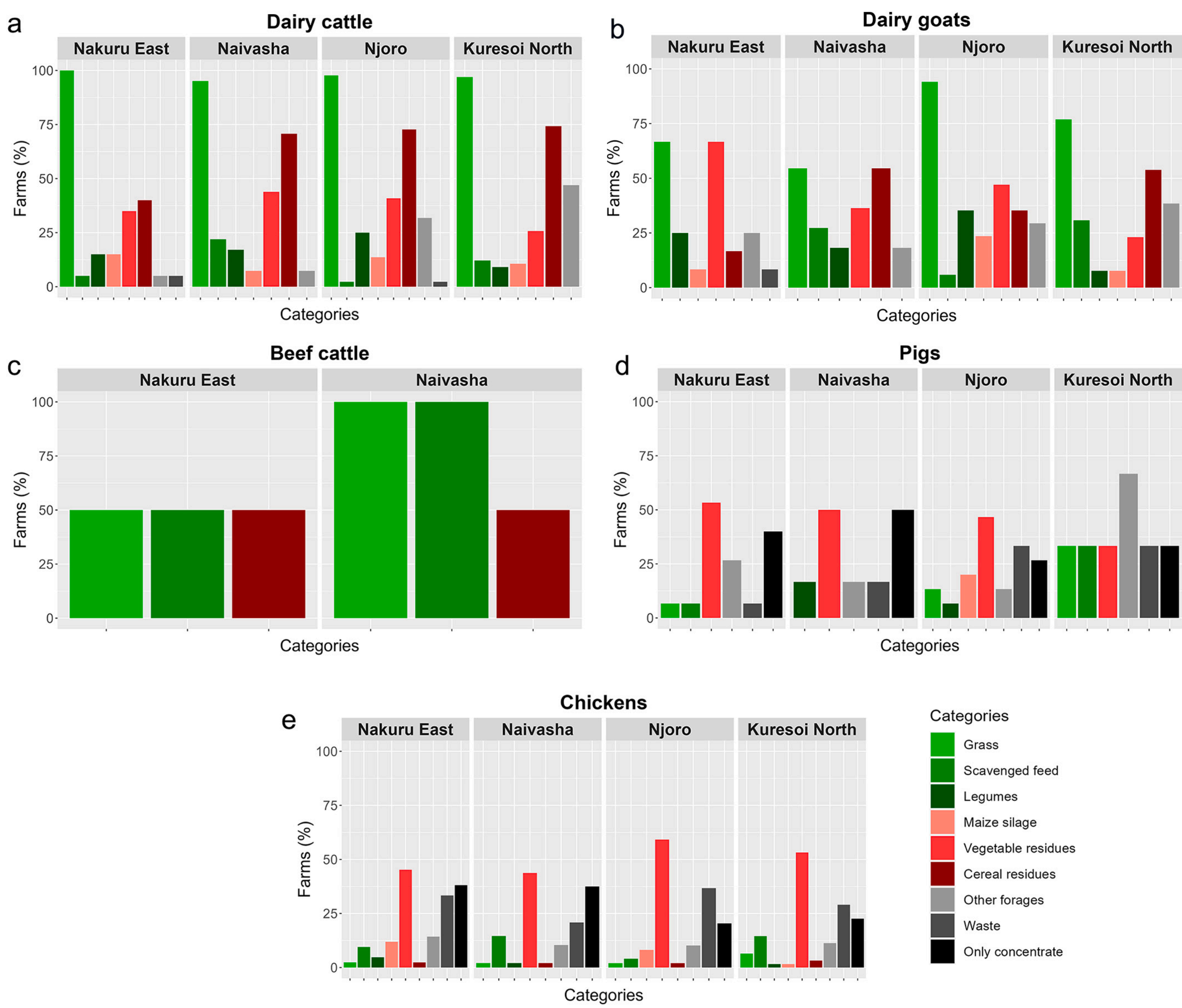

Fig. 2. Proportion of farms raising particular animal species using different fodder and forage categories across areas in Nakuru County.

Various other livestock species were observed across the study areas, including sheep, rabbits, ducks, geese, turkey, and donkeys. In Kuresoi North, sheep were prevalent among farmers (55 PoF), while other species were less commonly kept. Rabbits were predominantly raised by farmers in Njoro (29 PoF). Ducks and geese were frequently observed together, often scavenging on farms, with approximately 12.5 PoF in Nakuru East, Naivasha, and Njoro keeping these animals. Ducks were primarily raised for home consumption, whereas geese served dual purposes including security. Donkeys were absent from urban farms but found among peri-urban Njoro (15 PoF) and rural Kuresoi North farms (17 PoF), typically in small numbers per farm. The mean numbers observed for sheep, rabbits, geese, and turkey were 8.8, 9.2, 5.3, and 6.6 animals per farm, respectively. No significant differences were found in the numbers and TLU of other species across areas, except for ducks: Nakuru East and Naivasha differed significantly in duck populations, with averages of 3.5 and 10.1 ducks per farm, respectively ($P < 0.05$).

3.3. Feed management

3.3.1. Feed management in urban, peri-urban, and rural areas

As expected, all ruminant farmers used fodder and/or forage (Fig. 2a, b and c), while not all pig and poultry farmers used fodder and/or forage in their animals' diets (Fig. 2d and e). The absence of fodder and forage use for pigs and poultry was observed more frequently in urban areas than in peri-urban and rural areas. Household and market waste was more often fed to pigs in the peri-urban and rural areas than in urban areas. Dairy cattle received grass and cereal residues more often than dairy goats.

All dairy cattle in Nakuru East were fed concentrate feed and/or supplementary feed, while at all other farm areas it also occurred that no concentrate and supplementary feed was fed to dairy cattle (Fig. 3). When concentrate feed was fed, it was often in the form of compound feed, containing energy-rich and protein-rich ingredients, minerals, and vitamins. When ingredients were purchased separately, the emphasis was on energy-rich rather than protein-rich ingredients. Farmers in Nakuru East bought protein-rich ingredients more often than in the other areas, mainly when feeding dairy cattle (Fig. 3a). Agricultural

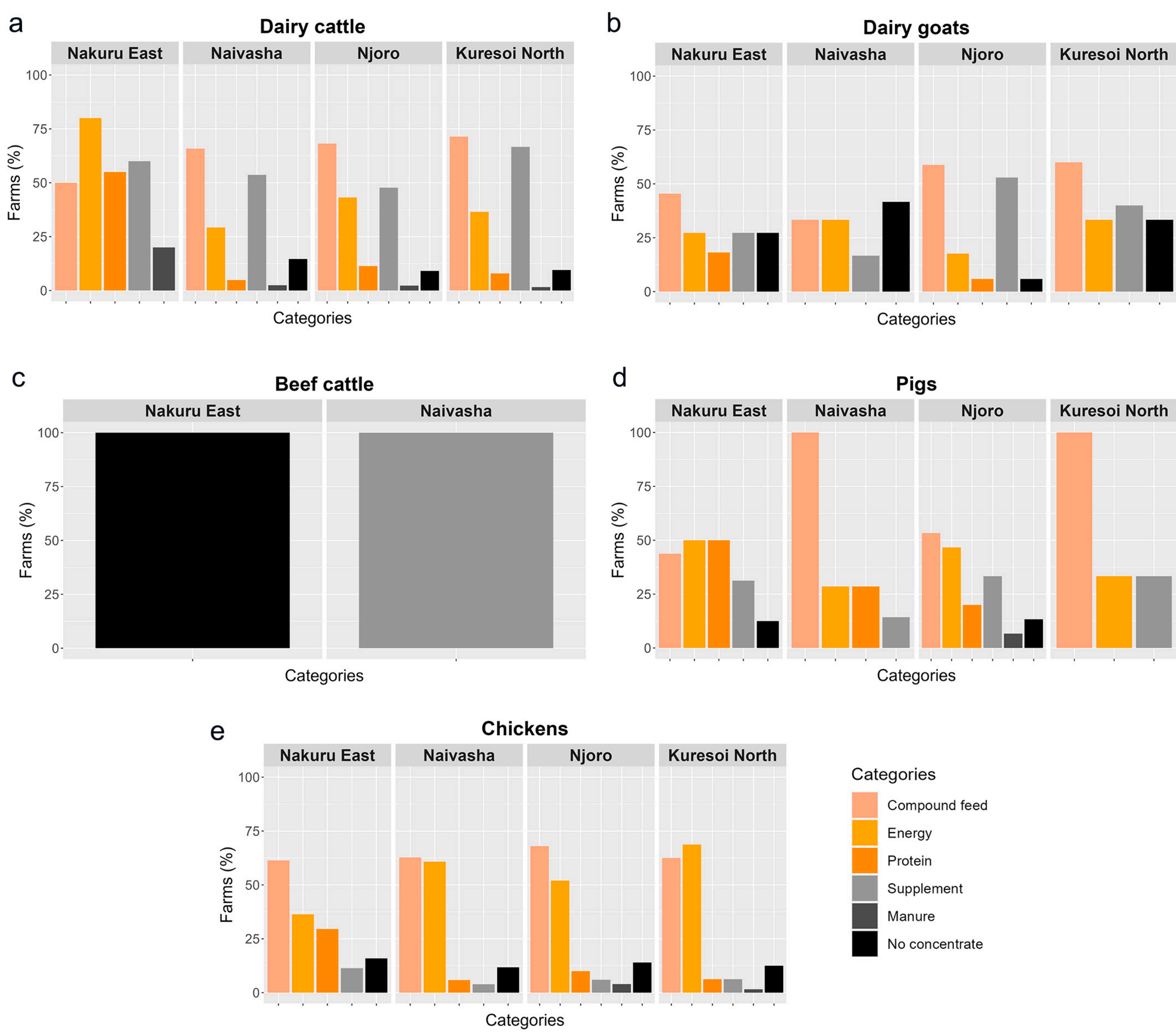

Fig. 3. Proportion of farms raising particular animal species using different concentrate feed categories across areas in Nakuru County.

supply stores ('agrovets') were present at all areas, and no correlation was found between distance to town and distance to agricultural supply stores.

3.4. Feed management per animal type

3.4.1. Dairy cattle – 171 farms

Most dairy cattle farmers fed a combination of grass and cereal residues (67 PoF; Fig. 2a), and the diet was often supplemented with a concentrate feed (91 PoF; Fig. 3a). Fodder was either produced on own farm or purchased externally, and 19 PoF grazed their cattle along roadsides. The most common grasses fed were Napier grass (81 PoF), Rhodes grass (53 PoF) and Kikuyu grass (30 PoF). Cereal residues fed included green maize stover (30 PoF), dry maize stover (44 PoF), oat straw (13 PoF), and weeds (26 PoF). In addition, farmers fed fodder legumes (e.g., lucerne, 12 PoF) and vegetable residues (e.g., beans, 16 PoF). Compound feed was the most common concentrate feed for dairy cattle, with 66 PoF using this product. When concentrate feed was purchased as individual ingredients and mixed on-farm, minerals and vitamins (51 PoF) were commonly used, along with energy-rich ingredients such as maize germ (27 PoF), wheat bran (18 PoF) and molasses (14 PoF). Protein-rich ingredients such as sunflower meal (11 PoF) and cotton seed cake (11 PoF) were purchased by a minority of farmers.

3.4.2. Dairy goats – 54 farms

Most dairy goat farmers fed grass (74 PoF) and combined it with either cereal residues (33 PoF) or vegetable residues (30 PoF; Fig. 2b). The diet was often supplemented with a concentrate feed (74 PoF; Fig. 3b). The most commonly fed grasses were Napier grass (48 PoF), Rhodes grass (37 PoF) and Kikuyu grass (8 PoF). Cereal residues fed included green maize stover (19 POF), dry maize stover (15 PoF), and weeds (22 PoF). In addition, farmers fed fodder legumes such as lucerne (17 PoF) and vegetable residues (e.g., beans, cabbage, potato peels). Compound feed was the most commonly used source of concentrate feed for dairy goats (52 PoF). When concentrate feed was purchased as individual ingredients and mixed on-farm, minerals and vitamins (28 PoF) were commonly used, along with energy-rich ingredients such as maize germ (22 PoF), wheat bran (9 PoF) and molasses (9 PoF). A few farmers purchased protein-rich ingredients such as sunflower meal (6 PoF) and cotton seed cake (6 PoF).

3.4.3. Beef cattle – 4 farms

Most beef cattle farmers fed fodder (50 PoF, e.g., Napier grass, Rhodes grass, maize stover) and/or grazed their cattle along the road (75 PoF; Fig. 2c). Beef cattle received no concentrate feed, only dicalcium phosphate and lime (Fig. 3c).

3.4.4. Pigs – 41 farms

Most pig farmers fed vegetable residues (46 PoF; Fig. 2d) and 34 PoF used solely concentrate feed (Fig. 3d). Both whole and by-products of vegetables such as cabbage (27 PoF), kale (24 PoF), potato (22 PoF), spinach (12 PoF), and tomato (10 PoF) were used. In addition, food waste of markets and households were fed (20 PoF). Compound feed was the most common source of concentrate feed for pigs, with 63 PoF using this product. When concentrate feed was purchased as individual ingredients and mixed on-farm, energy-rich ingredients such as maize germ (37 PoF), wheat pollard (37 PoF) and wheat bran (34 PoF) were commonly used. In addition, protein-rich ingredients such as cotton seed cake (27 PoF), sunflower meal (24 PoF) and soybean meal (17 PoF) were purchased.

3.4.5. Poultry – 210 farms

Most poultry farmers fed vegetables (residues; 49 PoF; Fig. 2e) and 28 PoF used solely concentrate feed (Fig. 3e). Vegetables and vegetable residues that were frequently fed were kale (43 PoF), cabbage (25 PoF), and spinach (7 PoF). In addition, food waste (29 PoF) and weeds (21 PoF) were commonly used to feed chicken. Compound feed was the main source of concentrate feed for chicken, with 67 PoF using this product. When concentrate feed was purchased as individual ingredients and mixed on-farm, energy-rich ingredients such as maize grain (39 PoF), maize germ (20 PoF) and wheat bran (6 PoF) were commonly used. Some farmers also purchased protein-rich ingredients such as fish meal (7 PoF), cotton seed cake (5 PoF), sunflower meal (5 PoF) and soybean meal (4 PoF).

3.5. Water sources

No significant differences were observed for water sources used between the different areas. Boreholes and rainwater were the most used water sources (48.1 % and 41.5 %, resp.). Other water sources used were rivers (4.7 %), water dams (4.0 %), springs (1.2 %), and piped water (0.5 %).

3.6. Manure management

At all areas, most of the manure was used to fertilize own farmland (Fig. 4). Additionally, some farmers sold part of their manure to other farmers, which was mainly observed in Nakuru East and Naivasha. Small fractions were used in the biodigester, burned, disposed of, or used as animal feed. Farmers using chicken manure as animal feed used it as a nitrogen source in dairy cattle diets. Additionally, chicken manure was used as substrates for maggots to mature, later serving as feed for chicken.

3.7. Traded livestock products

Fig. 5 shows the markets to which farmers in the various areas in Nakuru County delivered their animal sourced products. Most products ended up in the informal market. When products were sold in the formal market, this usually was milk. This was especially observed in peri-urban Njoro and rural Kuresoi North, where 21 and 48 PoF sold their milk in the formal market, respectively. Overall, 29 % of dairy farmers and 27 % of dairy goat farmers sold their milk in the formal market. To enter the formal market, milk was sold to cooperatives and processing plants, while in the informal market, neighbors were the most common buyers. The same was observed for eggs and meat, where neighbors bought the products most often. Pork always entered the market (formal or informal) and was never used only for home consumption.

4. Discussion

Previous studies have investigated the spatial variation in land use across urban, peri-urban, or rural areas, usually focusing on a single species or commodity. However, there is a lack of information on how urbanization influences resource use, nutrient cycling, and livestock species diversity within livestock farming systems. This study examined the impact of urbanization on these key aspects, covering most relevant livestock species on farms. While differences were observed between farm areas, they were less pronounced than initially hypothesized. Our findings indicate that urbanization is reshaping livestock farming practices, with a shift towards more intensive and market-oriented farming, resulting in a greater reliance on off-farm resources across all areas. Notably, farmers do not have smaller herd sizes of individual livestock species when located closer to the administrative centre, but maintain a smaller diversity of livestock species.

Urbanization in Nakuru city has led to land fragmentation, replacement, and intensification, as evidenced by our observation of small farms with very high stocking densities. Small scale farming areas are turned into new residential and industrial areas, while large scale farms are fragmented into small scale farms. Between 2010 and 2019, the number of farms smaller than 0.6 ha nearly doubled from approximately

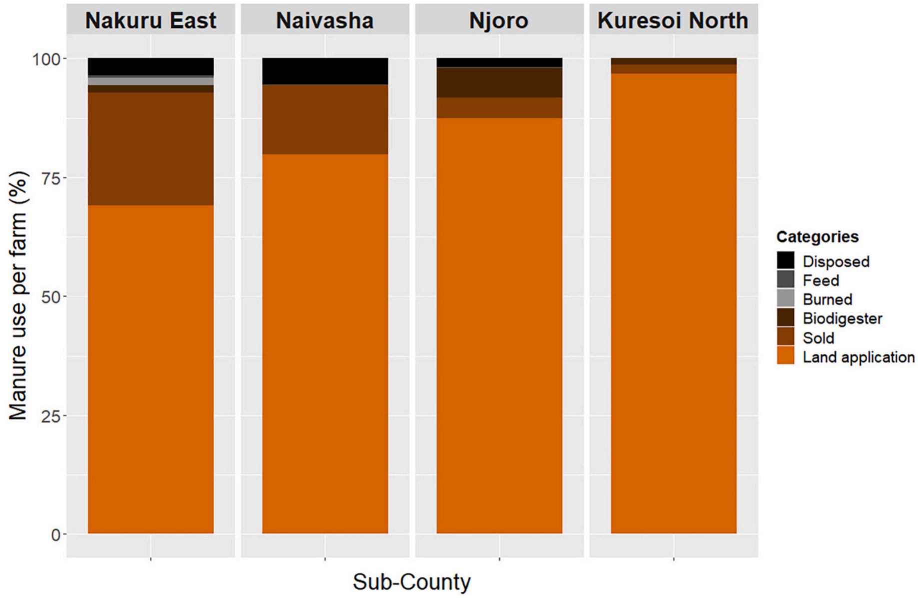

Fig. 4. Manure management across areas in Nakuru County.

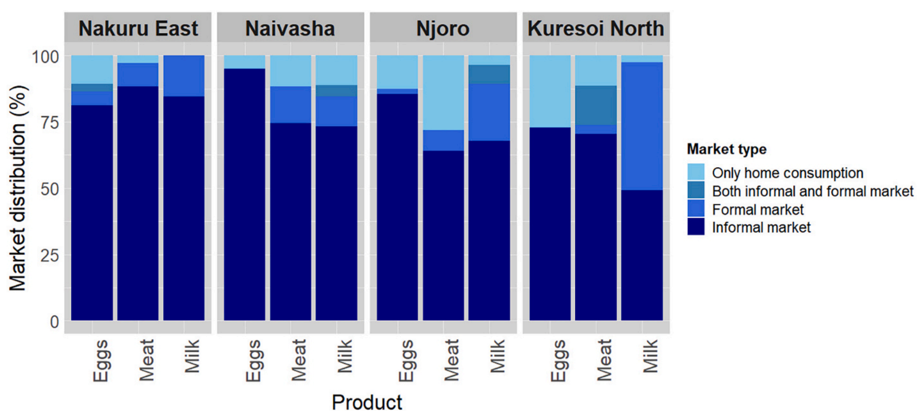

Fig. 5. Proportion of farms selling their products to formal and informal markets across areas in Nakuru County.

5900 to 11,700 farms in urban Nakuru (Willkomm et al., 2021). This trend is reflected in our results, showing an average farm size of 0.39 ha in Nakuru East. However, of all areas, urban Naivasha showed the largest farm size. Therefore, our proposed hypothesis that urbanization leads to small farm plots in urban areas is only partly supported. Naivasha has a larger land area, despite with lower population density compared to Nakuru East. This results in greater land availability, which can explain the larger farm size observed in Naivasha.

In all areas, available farmland was often dedicated to crop cultivation rather than to feed production for livestock, as producing perishable vegetables (e.g., spinach, kale, cabbage) for the market seems to be more profitable (Willkomm et al., 2021). When livestock are fed on external feed sources, limited land is needed (Ishagi et al., 2002). Therefore, the intensification of land use also includes maximizing livestock productivity on smaller plots of land, increasing reliance on off-farm resources, and optimizing resource use (Barrett et al., 2012; Duncan et al., 2013). This is in contrast with previous studies in Ethiopia, where rural farms rarely used external inputs and relied on natural grasslands and crop residues (Gebremedhin et al., 2014; Tegegne et al., 2013).

Our study showed that total herd size (in TLU) and livestock diversity were lower on farms in the urban area of Nakuru East than in other areas (Table 1). This contrasts with previous studies in East Africa that reported higher herd sizes (in TLU) in urban than rural areas (Wilson et al., 2021), higher herd sizes in urban than peri-urban areas (Gillah et al., 2013), or did not find a difference between urban and rural areas (Migose et al., 2018). However, most previous studies focused on only one animal species, whereas we included all animal species. Tropical livestock units vary between species, with chicken having the lowest TLU; it takes one hundred chickens to equal one TLU, while only half an exotic dairy cow is needed for one TLU. Nakuru East had several specialized poultry farms, resulting in a low total herd size (in TLU). In contrast, farms in other areas generally showed large livestock diversity, maintaining a combination of livestock species, which contributed to a higher total herd size (in TLU). The number of agricultural activities decreases when farms become too small, and opportunity costs of land and labor increase (Cobbinah et al., 2015; Mubea and Menz, 2012; Pribadi and Pauleit, 2015; Satterthwaite et al., 2010). This explains the differences observed in herd size between areas. Given that different species impact resource use differently, it is recommended to consider all livestock species when evaluating systems and sustainability.

It was our hypothesis that ruminants would be predominantly kept in rural areas due to their reliance on fodder and forage for which land is needed. Indeed, more farmers in rural areas kept dairy cattle than those in urban areas, resulting in a higher overall number of ruminants in rural areas. In areas with limited land availability, it is logical to transition from large livestock species, such as dairy cattle, to smaller livestock species, such as chicken (Steinfeld et al., 2006; van der Lee et al., 2018). Additionally, chickens are relatively easy to produce, require little capital, and have a high turnover rate, creating opportunities for urban residents to engage in poultry farming (Hundie et al., 2019). This likely explains the higher prevalence of poultry farms than dairy farms in urban areas.

Nevertheless, we observed that when dairy cattle and goats were kept, the average number of these animals kept by dairy cattle and goat farmers did not differ significantly across areas and land sizes. The underlying reasons for maintaining specific numbers of animals may vary by area. For instance, rural areas may face limitations such as labor availability, while urban areas may have challenges related to feed availability and/or manure disposal. Further research is needed to better understand the factors that influence the number and composition of animals kept in different areas.

Moreover, even in Nakuru East, where farm sizes are small, people still had an incentive to raise livestock, as evidenced by landless farms keeping livestock. This could be attributed to a longstanding interest in agriculture passed down through generations, coupled with the drive to ensure resilience through income diversification and enhanced food security (Lerner and Eakin, 2011). In addition, the influx of rural-to-urban migrants seeking urban employment in a saturated market can result in unemployment and poverty, prompting land-scarce urban residents to explore food self-sufficiency through livestock production as an option (Katongole et al., 2012; van Berkum, 2023).

The stocking rates in the urban areas were higher than in the peri-urban and rural areas, aligning with our hypothesis. However, the stocking rates were high across all areas compared to other studies conducted in Kenya (Ndungwa et al., 2018; Onduru et al., 2007; van der Lee et al., 2020). It appears that rural and peri-urban farms in Nakuru County are also intensifying land use to compensate for higher land rents, adopting market-oriented farming practices (Akinlade et al., 2016). These patterns indicate that the influence of urbanization extends beyond the borders of Nakuru city and Naivasha, emphasizing that urban, peri-urban, and rural areas are not uniform concepts. Instead, their interpretation varies based on the research context. Ideally, the gradient in this study would have been extended to rural areas that were less influenced by urbanization.

We hypothesized that access to external feed sources would be similar across areas, and our findings support this, as agricultural supply stores were available even in rural areas. This observation is consistent with that of van der Lee et al. (2020). Most farmers used compound feed as a source of concentrate feed in the diet of their animals. In Kenya, there is little transparency about the composition and quality of compound feeds, making it difficult for farmers to balance rations and optimize animal productivity. Therefore, some farmers purchased individual concentrate feed ingredients to create their own compound feed. However, energy-rich components such as maize germ and wheat bran were mainly purchased, while protein-rich ingredients were less commonly purchased. This may be due to the limited availability and high prices of protein-rich ingredients (Chia et al., 2020; de Groote et al., 2010). Training of farmers or extension officers in proper feed formulation is crucial for improving feed efficiency and animal productivity.

Kenya is not self-sufficient in the production of concentrate feed, leading to import of these products (van Ittersum et al., 2016; Vernooij and Veldkamp, 2018). Feed producers are only located in Kenya's major cities, including Nakuru (KMT, 2016). Therefore, the supply chain for farmers outside Nakuru is even longer, which increases the prices of these ingredients (Chamberlin and Jayne, 2013; Dione et al., 2014; Tiffen, 2006). This might explain why protein-rich ingredients were purchased more frequently in Nakuru East than in other areas. Cheaper and more readily available protein-rich ingredients could benefit the livestock sector in Nakuru. Additionally, the exact origin of these imported products is poorly documented, highlighting the need for further research to address this gap.

Our initial hypothesis expected surplus manure in urban centers to be predominantly disposed of through dumping, burning, or selling. However, the results indicate a predominant use of manure as fertilizer for own farmland across all areas. This suggests that contrary to our hypothesis, urban and peri-urban farmers are finding practical uses for the manure within their own agricultural activities. By integrating manure into their cropping systems, they reduce dependence on external fertilizers, which may reflect adaptive responses to rising fertilizer costs. Nevertheless, high stocking rates can lead to the accumulation of nutrients in the form of manure, posing public health risks and environmental hazards. Excessive application or mismanagement of manure can lead to nitrogen runoff, nitrate leaching, and eutrophication of nearby water bodies, posing risks to drinking water quality, especially in regions where well water is used for household consumption. Nitrate-contaminated water is linked to health risks, such as methemoglobinemia (i.e. blue baby syndrome), colorectal cancer, thyroid disease, and neural tube defects (Knobeloch et al., 2000; Ward et al., 2018). Additionally, air quality can be affected through the volatilization of ammonia, which contributes to local air pollution, and the denitrification of nitrogenous compounds, which releases nitrous oxide, a potent greenhouse gas that drives global climate change (Erisman, 2021; Ström et al., 2018).

To further understand the impact of manure utilization, it is possible to estimate how many animals can be supported per hectare to provide adequate nitrogen for plant growth. This is based on nitrogen excretion rates and typical nitrogen application rates for agricultural land. Our study showed that cropland was the dominant land use type and given that maize is the staple crop of Kenya (Muthoni and Nyamongo, 2010), we use maize as an example in this estimation. Dairy cattle in Africa excrete approximately 0.3 kg of nitrogen per day per cow through manure and urine, totaling 109.5 kg of nitrogen per year (IPCC, 2006). The typical nitrogen application rate for maize is around 190 kg N/ha/year (Yang et al., 2017). Therefore, we calculate that approximately 1.7 exotic dairy cows per hectare would be needed to supply sufficient nitrogen. This translates into 3.5 TLU/ha, which is lower than the observed stocking rates in our study (66.4, 19.3, 9.6, 6.3 TLU/ha for Nakuru East, Naivasha, and Kuresoi North, resp.). The high stocking rates result in accumulation of manure, which can lead to nitrogen runoff, nitrate leaching, and eutrophication of nearby water bodies if not properly managed.

Additionally, the land where the imported products originate from becomes degraded if not replenished with new nutrients (van Selm et al., 2023; Wang et al., 2022). This emphasizes the importance of enhancing nitrogen management throughout all stages of food production and implementing localized feed solutions to achieve sustainable livestock production (Chisoro et al., 2023; Rezende et al., 2023). Initiatives supporting the specialization and intensification of livestock production should facilitate the market integration of manure and enhance collaboration between livestock and crop farmers to improve resource use efficiency through environmentally friendly manure disposal (Roessler et al., 2016). Policy interventions could focus on manure trade, incentivizing sustainable manure application practices, and promoting circular farming initiatives. Such measures would improve resource use efficiency and reduce the environmental impacts of nutrient surpluses.

Our hypothesis suggested that a higher proportion of animal source products would enter the informal market due to lower prices offered in the formal markets (Kanire et al., 2024; Migose et al., 2018; van der Lee et al., 2018). Our findings confirm this trend, showing high sales in the informal sector. Another factor contributing to high informal market sales may be the resource-poor farmers' preference for immediate payment, unlike the bi-weekly or monthly payments offered by cooperatives and processors (van der Lee et al., 2018). Urbanization also brings challenges such as stricter food safety and quality standards (Blackmore et al., 2022; de Bruin et al., 2021; Oosting et al., 2014; van Berkum, 2023), prompting some producers to bypass these regulations by selling on the informal market rather than formal market. Our findings showed that milk was the predominant product sold in formal markets, particularly in peri-urban Njoro and rural Kuresoi North. This can be explained by the fact that farmers in remote areas do not have access to as many marketing channels as those in urban areas and therefore have to deliver the milk to cooperatives (van der Lee et al., 2020). By channeling milk to the formal market, peri-urban and rural farms contribute to the increasing urban demand (Makoni et al., 2014).

5. Conclusion

This study demonstrates that urbanization in Nakuru County influences livestock farming systems. The anticipated differences between urban, peri-urban, and rural farm areas were not as pronounced as initially hypothesized, since a shift towards more intensive and market-oriented farming practices were observed across all areas. Urban farms face land scarcity, leading to higher stocking rates and specialization in smaller livestock species like poultry. This results in a high dependency on external inputs, while peri-urban and rural farms are also increasingly adopting market-driven approaches with a similar dependency on external inputs. The presence of agricultural supply stores across all areas supports uniform access to external feed sources, although high prices and limited availability of protein-rich ingredients pose challenges.

The accumulation of nutrients from purchased feeds disrupts nutrient cycles, highlighting the need for improved nitrogen management and localized feed solutions. The study underscores the importance of considering all livestock species when evaluating systems and sustainability. Our comprehensive approach revealed variations in herd size and livestock diversity, that single-species studies seem to overlook, providing more accurate insights into system performance and management. Overall, our study provides valuable insights into the sustainability of livestock farming systems in the context of rapid urbanization. Future research should focus on developing localized feed solutions, enhancing nitrogen management, and supporting market integration to foster sustainable livestock production in urbanizing regions.

Ethical approval

Ethical approval for this study was obtained from the Egerton University Research Ethics Committee (project reference: EUREC/APP/121/2021). The Egerton University Research Ethics Committee is accredited by the National Commission for Science, Technology and Innovation (NACOSTI) in Kenya.

CRediT authorship contribution statement

Dagmar J.M. Braamhaar: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jan van der Lee:** Writing – review & editing, Supervision, Conceptualization. **Bockline O. Bebe:** Writing – review & editing, Resources. **Simon J. Oosting:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dagmar Braamhaar reports financial support was provided by Dutch Ministry of Agriculture, Nature and Food Quality. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2025.104297.

Data availability

Data will be made available on request.

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