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# ESTIMATION OF TOTAL WATER USE REUIREMENTS IN EWASO NG'IRO NORTH CATCHMENT AREA (ENNCA)

## USING THE LIVESTOCK WATER FOOTPRINT

CETRAD Centre for Training and Integrated Research in ASAL Development
PIK
MID-P Collective Action: Resilient Society
NDMA National Drought Management Authority

SEI Stockholm Environment Institute

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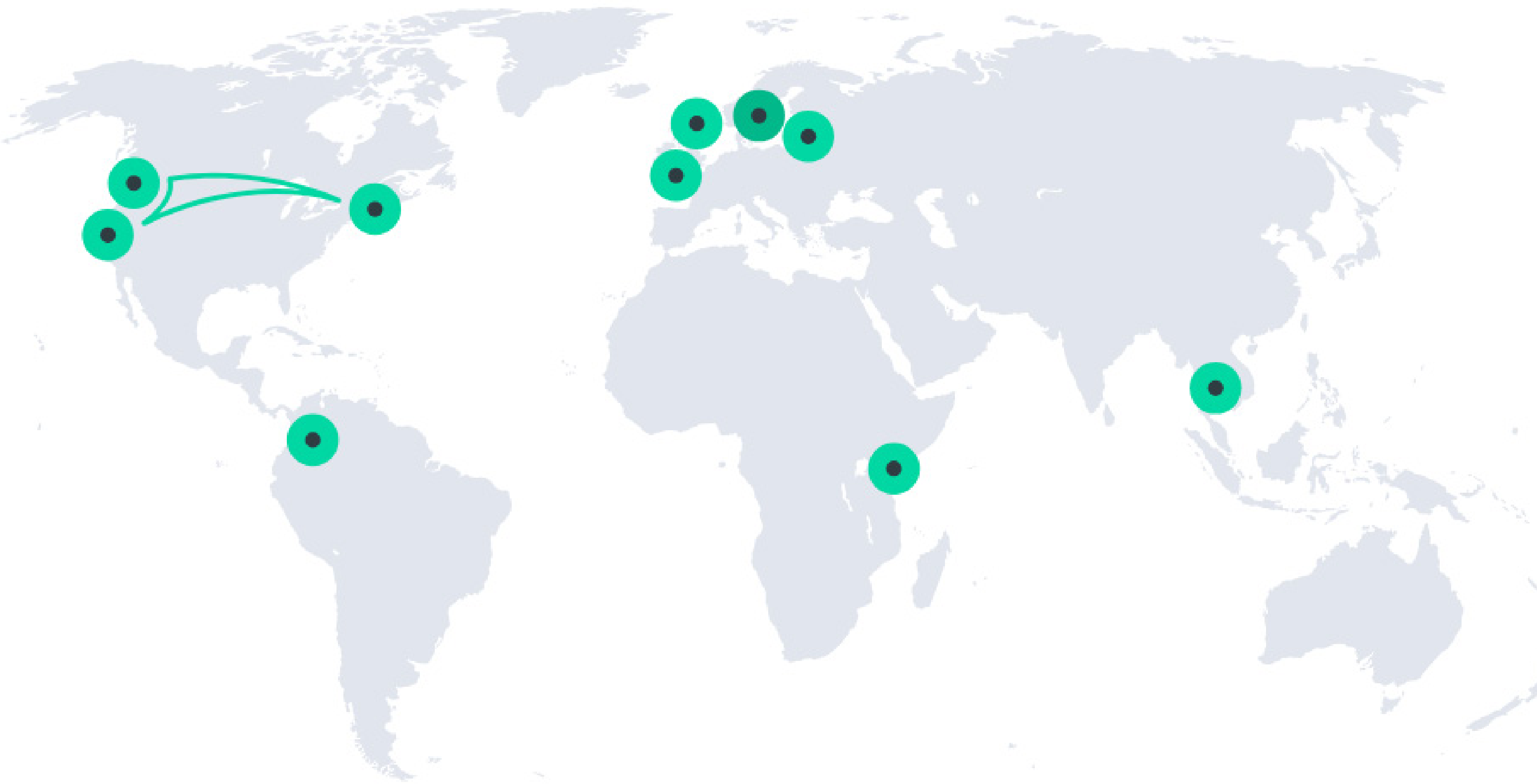

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## About the Project

# Applying the water-energy-food nexus to promote ecosystem-based adaptation in the Ewaso Ng'iro North Catchment, Kenya

This project seeks to support the Government of Kenya, five county governments (Laikipia, Samburu, Isiolo, Meru and Nyeri), local communities, and agro-based private enterprises to promote ecosystem-based adaptation practices and integrated planning for water, energy, agriculture and land use for resilient livelihoods in the Ewaso Ng'iro North Catchment Area.

The project seeks to apply ecosystem-based adaptation (EbA) and the nexus approaches to facilitate the co-production of resilient water-energy-food (WEF) knowledge with stakeholders (policymakers, local community groups, private sector, and non-governmental organizations) to inform decision and policymaking.

The project will contribute towards several development objectives which are in line with the Kenya Vision 2030 priorities, the Ewaso Ng'iro North Development Area (ENNDA) Integrated Regional Development Plan (2010-2040), the ENNDA catchment management strategy and the reformulation and implementation of CIDPs. These include increasing food security, especially pastoral livestock production; resilience through livelihoods diversification; employment creation through EbA solutions; agricultural growth; the conservation and safeguarding of critical habitats, including wildlife-protected areas and community wildlife conservancies. At the governance level, the nexus approach is expected to promote cooperation among actors and policy coherence across "policy silos", i.e. sectors, levels and scales and the key added value of the nexus approach is in integrating across the various plans and strategies, promoting synergies and generating co-benefits.

## Expected results

- WEF nexus models and development scenarios for Ewaso Ng'iro North Catchment Area (ENNCA)
- Identification, validation, and promotion of innovative Ecosystem-based nexus solutions among key stakeholders in the ENNCA region
- Increased awareness of cross-sectoral interactions (water, energy, agriculture, and land) during the implementation, upscaling, out scaling, and transfer of ecosystem-based nexus solutions at the sub-national and national level

# BACKGROUND

Population growth, rapid urbanization and rising income levels in low and middle income countries (LMICs) are driving an increase in demand for animal source products ( Latino, Pica-Ciamarra, and Wisser 2020). Increasing livestock production is one of the available pathways for meeting the rising demand for animal source foods in LMICs. Indeed, intensification of livestock production as a way of achieving economic growth alongside satisfying the growing demand for animal source foods is envisioned in development strategies such as Comprehensive Africa Agriculture Development Programme CAADP and Kenya's vision 2030. However, these strategies also seek to achieve sustainability targets through the optimal use of natural resources in while meeting the diverse and competing demand(Bosire et al. 2022).

An increase in livestock production will mean increased demand for land and freshwater in livestock production which will affect socio-economic, political and natural resource spheres. This is especially evident given the competing demand for land and freshwater (Bosire et al. 2022) experienced globally (Bac, Badulescu, and Lang 2011; Chertow 2000). Sustained growth in livestock production to meet the growing demand for animal source foods will therefore be determined by the availability of adequate land and freshwater to support agricultural production (Stroosnijder et al. 2012; Wirsenius, Azar, and Berndes 2010).

Fresh water is an important factor in agricultural production, a sector that accounts for up to 70% of global water withdrawal. A third of the water consumed in agriculture is associated with livestock production. This demand for freshwater by the livestock sector is likely to increase with the growing demand for animal source foods(Ibidhi and Ben Salem 2020; Mekonnen and Hoekstra 2012), driving pressure on the agricultural sector in supplying food, feed and biofuels. Projections indicate that two-thirds of the world population will face water scarcity by 2025(Mekonnen and Hoekstra 2012). This increase in freshwater demand therefore needs to be comprehensively assessed and appropriate solutions proposed. The awareness of the need to preserve freshwater resources is growing among various stakeholders including researchers, policy makers and government representatives. To inform on the most optimal governance and to meet the various objectives of the stakeholders in freshwater utilization for agriculture and industry, preservation of freshwater resources, a strong evidence base on current and projected water use is required.

The water footprint (WF) is a metric that provides key information that facilitates optimal freshwater management and governance. The WF is an indicator that quantifies water use in a manner that allows for an understanding of the impacts of human activity on freshwater resources(Mekonnen and Hoekstra 2012; Zhang, Hoekstra, and Mathews 2013). The water footprint measures water use in producing consumer goods, expressed as the volume evaporated or polluted(Mekonnen and Hoekstra 2011). The WF is broken down into three components: green, blue, and grey water footprints. Green water comes from rainfall and supports rainfed crops, while blue water is associated with ground water sources such as rivers, lakes, and aquifers, and in the context of agriculture is typically used for irrigation. Grey water reflects water quality, indicating the volume needed to dilute pollutants to safe levels.

The water footprint of a product is the direct and indirect amount of water consumed and polluted in all the processing stages of its production (Galli et al. 2012; Hoekstra, Chapagain, and van Oel 2019; Vanham 2013). For livestock, the water footprint includes water for feed which is mainly indirect and the direct portion of the water which is associated with drinking and service water (Chapagain and Hoekstra 2003). Given the significant amount of freshwater consumption in livestock production, it is important to determine the actual demand for fresh water in livestock production. This will inform strategies that will ensure optimal livestock productivity per unit of freshwater (Bhagat et al. 2020; Bosire et al. 2022; Heinke et al. 2020; Ibidhi and Ben Salem 2020).

The livestock water footprint, allows determination of water consumption in livestock and inadvertently ensures enhanced governance in freshwater use for livestock production(Bhagat et al. 2020; Mekonnen and Hoekstra 2012; Zhang et al. 2013). The water footprint of live animals consists of direct water footprint of drinking and service water and the indirect water footprint of feed(Bhagat et al. 2020).

The water footprint of an animal can be expressed as m3/y/ animal or m3/animal when summed up for the entire life of the animal. The latter is most useful for beef, sheep, broiler chicken, pigs, and goats which provide products after slaughter. For dairy cattle and layer chicken m3/y/animal is most appropriate as these annual water footprints can be compared to annual milk/eggs pro production (Bhagat et al. 2020).

The largest contributor to the livestock water footprint is the feed production. This is evident in the assessment approach which takes into consideration three factors: feed conversion efficiency, diet composition and the feed origin (Gerbens-Leenes, Hoekstra, and Van Der Meer 2009; Mekonnen and Hoekstra 2012). Feed conversion efficiency measures the amount of feed to produce a given amount of meat, eggs, or milk (Mekonnen and Hoekstra 2012). In Kenya, the average slaughter age is 6 years, leading to a longer duration of livestock rearing and consumption of resources. Many of the animals are reared in the extensive system which is characterised by longer distances between their housing units and the feeding and watering areas, leading to relatively higher maintenance needs. The animals have a lower feed conversion rate where they need a greater proportion of feed to convert to a unit increment of meat as shown in the extended periods to reach slaughter weight especially in grazing systems. A clearer demonstration of improved efficiency is whereby feed conversion efficiency improves from grazing systems through mixed systems to industrial systems yielding a smaller water footprint in industrial systems (Mekonnen and Hoekstra 2012).

Composition of feed eaten by animals: an increase in the proportion of feed concentrates in the feed composition translates to a higher water footprint compared to diet composition with higher proportion of roughages (grass, crop residues, and fodder) which have relatively smaller water footprint. The fraction of animal feed concentrates increases while the fraction of roughages decreases from grazing through mixed to industrial systems and therefore grazing and mixed systems have a lower water footprint as compared to industrial systems(Blackburn 2003). The water footprint of concentrates is approximately five times larger than the water footprint of roughages. The roughages and residues have a lower water footprint as the main proportion of the water footprint is assigned to the cereals and grains which constitute the bulk of the concentrate and compounded feed (Mekonnen and Hoekstra 2012).

Feed origin: The water footprint varies depending on the production region, feed composition, and origin of the feed ingredients. The water footprint for beef in an industrial production system may rely on to blue (irrigation) water used to grow feed in a different region. The feed is then transported into the industrial production system thereby leading to a higher blue water footprint of production than is associated with a rainfed feed production process. In grazing systems on the other hand, livestock water footprint is mainly associated with a green water footprint linked to precipitation centered pasture rearing in the extensive systems (Mekonnen and Hoekstra 2012).

By partitioning the water footprint into the three components, this indicator is appropriate for use in multidimensional assessment of resource use. Addressing the water use challenges from only a total water footprint volumetric value, does not allow for a clear understanding of the context in which the freshwater use is constrained or can be enhanced. Assessing the green, blue and grey water footprint components and location at which they are drawn from allows for this contextualisation and provision of apt solutions to freshwater use challenges (Mekonnen and Hoekstra 2012). This distinction is especially important in addressing social and ecological impacts of water use at a certain location which depend on the scarcity and alternative uses of water at that location (Mekonnen and Hoekstra 2012).

Increasing water productivity in livestock production systems is therefore crucial in addressing the looming challenge of water scarcity and resulting social and ecological impacts in locations where there is livestock production (Heinke et al. 2020). Livestock water productivity has been found to differ by large magnitudes among, livestock types, production systems, and locations indicating potential for improvement(Heinke et al. 2020). Opportunity to improve LWP can be achieved by improving both feed water productivity (FWP) and feed use efficiency (FUE) through better crop and livestock management (Bosire et al. 2022; Heinke et al. 2020). Improving LWP in ruminants is often limited in industrial production systems which are already characterized by high yielding crop production for feed and improved livestock breeds (Bosire et al. 2022; Heinke et al. 2020).

# The ENNCA project

Kenya aims to achieve middle income status through the Vision 2030 plan and integrated SDG and NDC implementation and their targets on climate change mitigation and adaptation. The Ewaso Ng'iro North Catchment Area (ENNCA) located in the arid northern Kenya, consists of 10 Counties with an estimated population of 4 million people. The ENNbA project is implemented in the five Counties of Laikipia, Samburu, Isiolo, Meru and Nyeri, where rapid transitions in agriculture, energy systems and water and land use are ongoing (figure 1). Over three (3) million people and large numbers of livestock, wildlife and ecosystems rely on the Ewaso Ng'iro North River, the only perennial river within the ecosystem. As a consequence of the Kenya Vision 2030 and its flagship projects (a Mega dam along the Ewa so Ng'iro River, the Isiolo City resort, and the Lamu Port-South Sudan-Ethiopia¬ Transport Corridor), the prevailing competition among different water, land, biomass and energy users in the basin is projected to intensify further. Additional pressures arise from upstream commercial agriculture expansion, population and urban growth and climate variability (in particular droughts and floods) and change. These factors in combination lead to increased abstraction of water for irrigation, thereby critically reducing the water flow during the dry season, land degradation, loss of ecosystems and eventually loss of water-, energy- and food security.

The ENNbA project is applying a combination of Ecosystem-based Adaptation (EbA) and the nexus approach for addressing the combination of pressures in an integrated and sustainable way. The project is generating evidence that coordination and cooperation across sectors (water, energy, agriculture / land, and environment / ecosystems) and scales (local and national) can promote synergies and bring benefits over and above taking a single sector approach and that ecosystems can serve as "natural infrastructure" and that an EbA nexus approach can strengthen resilience. This knowledge is being co-developed with stakeholders so it can be applied in decision- and policy making, ensuring policy coherence and eventually mainstreaming an EbA nexus approach into policies, strategies and action plans.

This component of the project seeks to assess LWF in the ENNCA region, project livestock numbers in the ENNCA region using LWP data for projection of future LWF, assess past and future LWF trends across three production systems (arid, semi-arid, and humid) and their implications on ecosystem services and livelihoods in the ENNCA region.

**This component will be realized through the following objectives:**

1. Assessment of Livestock Water Footprint (LWF) in ENNCA across three production systems (arid, semi-arid and humid systems)

2. Mapping of livestock in the ENNCA region using data on livestock water productivity (LWP) derived from the Global Livestock Production System (GLPS) and other relevant databases

3. Analyse the changes and trends (past, 2000-2020 and future, 2021 - 2030) in Livestock Water Footprint (LWF) and assess the implications to ecosystem services and livelihoods in ENNCA (including the five project counties (Nyeri, Meru, Laikipia, Isiolo and Samburu).

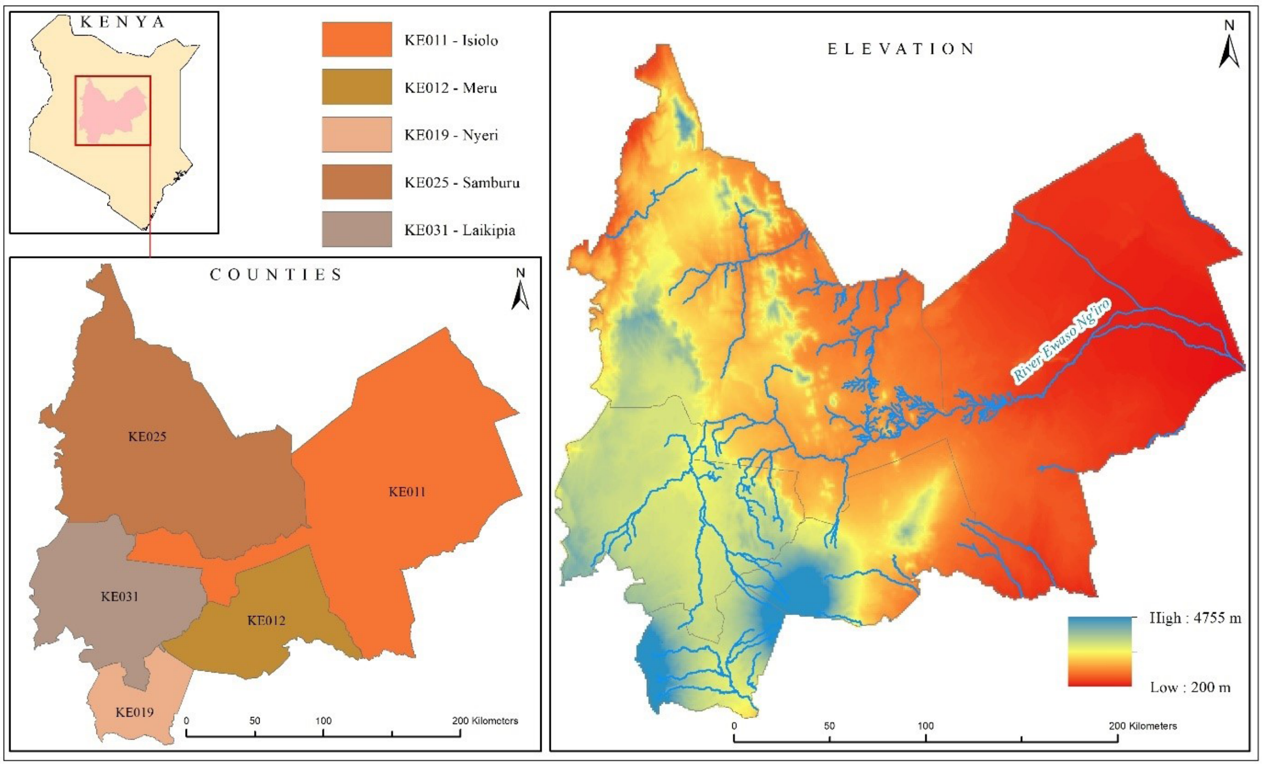


*Figure 1: Project area showing the five countries of focus by the project: Isiolo, Meru, Nyeri, Samburu and Laikipia and the Ewaso Ng'iro catchment.*

# Rationale

Livestock keeping is an important economic activity in the ENNCA region and will be competing for freshwater resources in the Ewaso Ng'iro North catchment area. It is therefore important to determine the current and projected livestock water footprint in the region to inform strategies to optimize livestock water productivity. The findings are further important for informing future planning of overall water demand by ensuring that the larger water needs from livestock feed requirements is captured. Additionally, this will help in outlining livestock water use relative to the available freshwater resources and competing demand for freshwater resources by other planned economic activities.

# Materials and Methods

Our approach is aimed at providing a comprehensive overview of the freshwater needs in the ENNCA. First, the outline of the production systems within the 5 counties, Isiolo, Meru, Samburu, Nyeri, and Laikipia, in the ENNCA project was provided. This is followed by the estimation of the livestock densities within the counties and delineating them across the production systems (figure 2). These estimates highlighted the trends in livestock distribution and densities from 2000 to 2020 and then projected to the year 2030. Thirdly, the total annual production of meat and milk from ruminants was estimated for each of the counties and production systems. We finally estimated the water footprint within each of the counties using the production systems as a defining measure and analysed changes over a 30-year period.

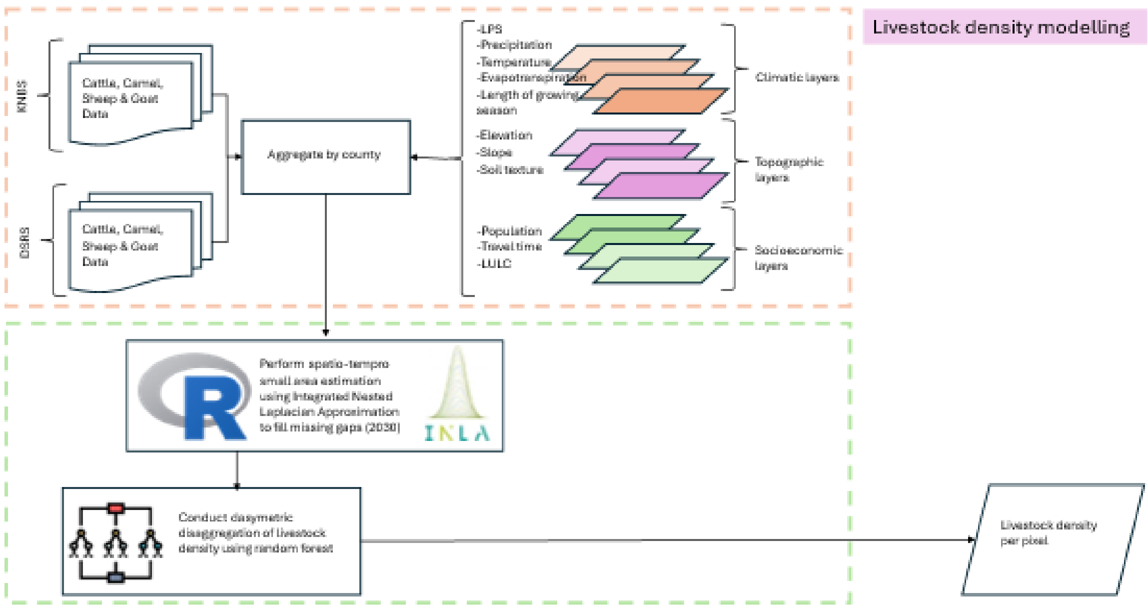


*Figure 2:Flow diagram describing the methods used in assessing the water footprint of livestock production for cattle, shoats and camels across three livestock production systems and projected to the year 2030.*

## Determining production system spatial extent within the ENNCA

We used the Global distribution of ruminant livestock production systems V5 developed by FAO (Robinson et al 2018). This product was generated based on the understanding that livestock production relies on the environment that provides fodder and feeds as well as the resources allocated to the livestock production. The spatial layer was downloaded and clipped for our area of interest.

## Estimating livestock numbers and densities within the ENNCA

Livestock numbers were collated from various sources that include the Kenya National Bureau of Statistics (KNBS), 2009 and 2019 census data, KNBS estimates from 2015-2022, publications and reports (Behnke & Muthami 2011, Makokha & Witwer 2013, and Ogutu et al 2016). Livestock numbers were obtained at different administrative units (national, provincial, county, sub-county) and livestock production systems. Using the ratio of livestock numbers per livestock production system in a county and the area livestock numbers were redistributed to the county administrative units. Sub-county livestock number were also aggregated to the county units. From the redistribution, livestock estimate by county were determined from 1977 to 2022.

Several socio-economic and ecological variables were also selected and downloaded as spatial layers. They included temporal (population, actual evapotranspiration, length of growing seasons, land use land cover, temperature, precipitation, soil moisture,) and static layers (digital elevation model, landform, travel time, livestock production systems and slope). Future land use land cover was modelled using MOLUSCE plugin in QGIS. These layers were then resampled to 1km-by-1km grid cells. The raster layers were later used to disaggregate the livestock data. The medium values were extracted by county and then used to run a spatio-temporal model to predict livestock numbers for the years 2000, 2010, 2020 and 2030 per county.

A spatio-temporal model to predict livestock numbers for 2000, 2010, 2020 and 2030, was then developed. The model assumed that the livestock numbers followed a poison distribution expressed as follows.

$$\mathbf{Livestock_{tj} \sim Poisson\ (\mu_{tj})}$$

$$\mathbf{\log\ (\mu_{tj}) = \beta_0 + \beta \times X_{tj} + v_{tj}}$$

Where Livestocktj is the county j livestock numbers in year t, µtj the expected number of livestock in county j and year t, β0 is the intercept matrix, β the coefficient matrix, Xtj is the covariate matrix and vtj is the residual.

$$\mathbf{v_{tj} = \varphi \times v_{t-1,\,j} + u_{tj}}$$

The residual has two components φ × vt-1, j which determines the temporal variation and utj which determines how livestock numbers vary spatially over the years. This model was implemented using R-INLA package in R. Using the covariate spatial raster layers, predict livestock numbers for 2000, 2010, 2020 and 2030 were disaggregated to pixel level using Random Forest (see figure 1).

## Total annual meat and milk production in the ENNCA

The meat production ( $P_{meat[a,s]}$, ton/yr) per animal in category a (beef cattle, camel, sheep and goat) in production system s is estimated by multiplying the carcass yield per slaughtered animal ( $CY[a,s]$) by the annual number of animals slaughtered ( $SA\ [a,s]$ ):

$$P_{meat[a,s]} = \dot{CY}\ [a,s] \times SA\ [a,s] \quad (1)$$

The carcass yields for cattle and shoats were obtained from Bouwman et al. (2005) and Bosire et al. (2022).

The number of animals slaughtered in each production system was calculated by multiplying the total animal numbers $Pop[a,s]$ by the net offtake rate : $\dot{OR}\ [a,s]$

$$SA_{[a,s]} = Pop[a,s] \times OR\ [a,s] \quad (2)$$

Total annual milk production (tonne) per animal for each production system was calculated as follows:

$$P_{milk}[a,s] = \dot{MY}[a,s] \times \dot{DC}\ [a,s] \quad (3)$$

where $P_{milk}$ represents the production of milk per cow or shoat in production system s, $\bar{MY}[a,s]$ (kg) is the milk yield per dairy cow in each production system and is the number of dairy cows in each production system. The yield estimate is derived by assigning the yield attributed to the predominant breed i.e. Zebu, crossbreed or exotic, as the milk yield estimate within a specific production system(King 1983; Ngigi 2011; Rege et al. 2001; Staal et al. 2001).

## Volume and composition of feeds

Due to the varied nature of feed composition across systems, daily feed intake was estimated using information on diet composition and quality, feed conversion efficiency and milk and/or meat production. The estimation of quantities of feed, feed composition, sources of feed and feed yields per unit area within each production system was made by combining feed conversion ratio, per animal output and feed composition, with the estimates of livestock numbers from section 1 above.

$$Feed_{[a,s]} = FCE_{[a,s]} \times P_{[a,s]} \tag{4}$$

$Feed_{[a,s]}$ (ton/yr) is the total amount of feed consumed by an animal in category a in production system s, $FCE_{[a,s]}$ is the feed conversion efficiency (kg dry mass of feed/ kg product) for animal $a$ in production system $s$ and $P_{[a,s]}$ (kg/yr) is the amount of product (milk, meat) produced by animal $a$ in production system $s$ .

## Water footprint estimation

The water footprint of an animal and its three components are expressed in terms of m3/yr/animal, or, when summed over the lifetime of the animal, in terms of m3/animal. The water footprint of an animal can thus be expressed as:

$$WF[a,s] = WF_{feed}[a,s] + WF_{drink}[a,s] + WF_{serv}[a,s] \tag{5}$$

where $WF_{feed}[a,s]$ , $WF_{drink}[a,s]$ and $WF_{serv}[a,s]$ represent the water footprint of an animal in category a in production system s, related to feed, drinking water and service water consumption, respectively. The water footprint for drinking and servicing estimates were taken from Mekonnen and Hoekstra (2010).

### Estimating the Water footprint of feed $(WF_{feed})$

The water footprint of an animal related to the feed consumed consists of two parts: (i) the water footprint of the various feed ingredients; and (ii) the water that is used to mix the feed ingredients:

$$WF_{feed}[a,s] = \sum_{p=1}^{n} \left( Feed[a,s,p] \times WF^{*}_{prod}[p] \right) + WF_{mixing}[a,s] \tag{6}$$

where $Feed[a,s,p]$ is the annual amount of feed ingredient p consumed by an animal in category a in production system s (tonne/yr) and $Feed[a,s,p]$ is the volume of water consumed by mixing the feed for an animal in category a in production system s (m3/yr/animal). $WF^{*}_{prod}[p]$ is the average water footprint of the various crops, roughages and crop-by products p (m3/ton) weighted over the production locations.

$$WF^{*}_{prod}[p] = \frac{P_{[p]} \cdot WF_{prod}[p] + \sum_{n_e} VWI[p]}{P_{[p]} + \sum_{n_e} P_{n_e}}$$

where $WF_{prod}[p]$ (m3/tonne) is the water footprint of feed product $p$ produced in the counties of the ENNCA or inside Kenya , $VWI[p]$ (m3/tonne) is the virtual water import of product $p$ from the feed exporting nation $n_e$ , $P[p]$ is the quantity of feed product $p$ in the counties or in Kenya (tonne/yr) and $P_{n_e}$ is the quantity of the imported feed product $p$ from the exporting country $n_e$ (tonne/yr).

### The water footprint of feed ingredients

The water footprints of the various crops, roughages and crop by-products ( $WF^*_{prod}[p]$, m3/ton) that are eaten by cattle and shoats have been calculated following the methodology of Chapagain and Hoekstra (2008). The water footprints of feed crops were estimated using a crop water use model that estimates crop water footprints at a 5 x 5 arc minute spatial resolution globally (Mekonnen and Hoekstra 2011)and aggregated to the scale of the three previously described Kenyan production systems. Grey water footprints were estimated by considering only leaching and runoff of nitrogen fertilizer (Mekonnen and Hoekstra 2010) .

## Mapping

The computations above were done using spatial layers using R version 4.3.3. The layers were mapped using ArcGIS 10.8.

# RESULTS

## Livestock production systems in the ENNCA region

The area experiences three livestock production systems (LPS) namely arid, semi-arid and humid. The most dominant LPS within the ENNCA region is arid. However, the proportion varies from county to county (See figure 3). The area under arid zone is higher in Isiolo and Samburu representing 99% and 83 % respectively, of the total area. Laikipia is dominantly a humid zone covering 93% of its area. Nearly half (57%) of the area in Nyeri county is semiarid while the other half is humid. Arid, semiarid and humid zones cover 43%, 33% and 24% respectively, of the area in Meru County (Table 1).

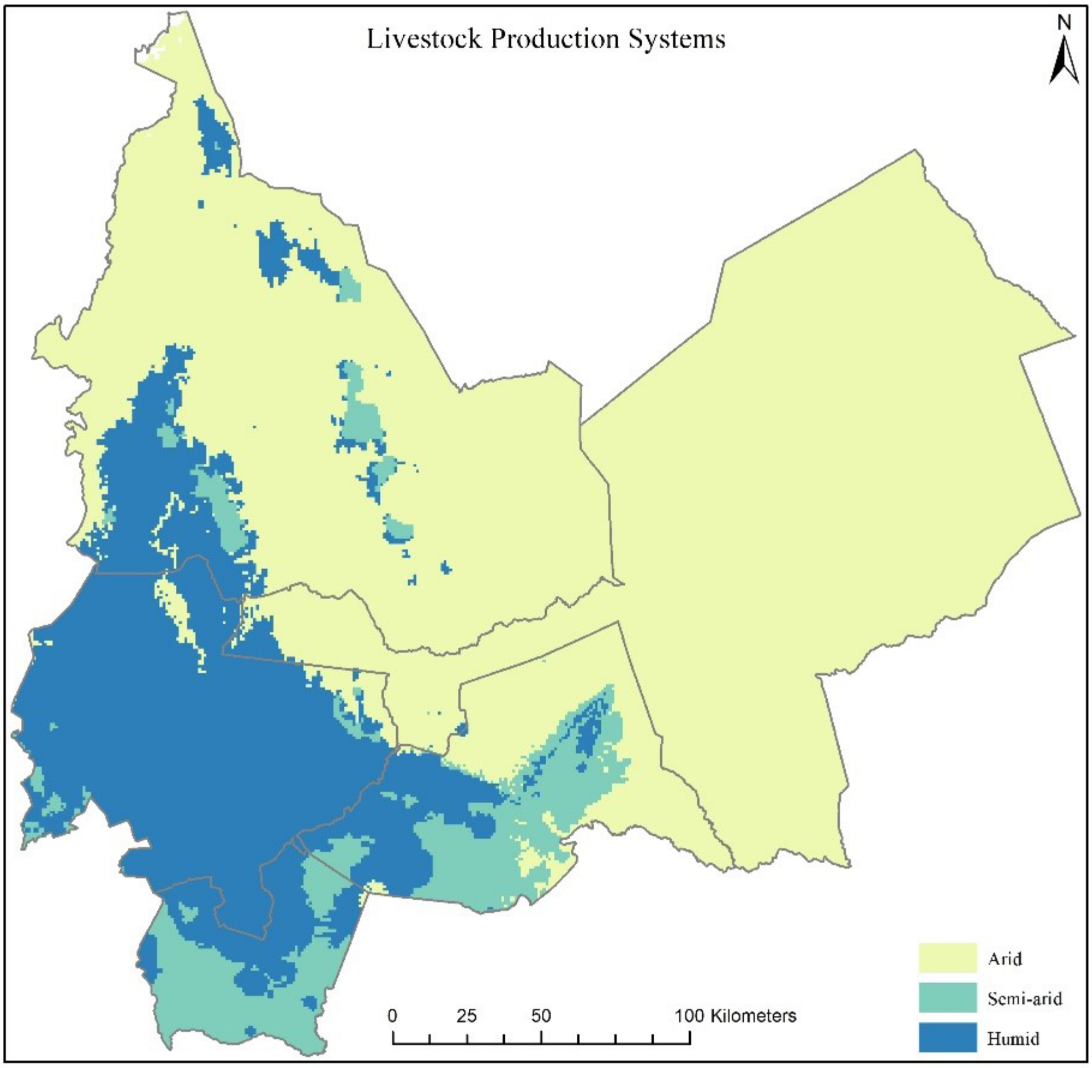


*Figure 3: Map of the ENNCA showing the three Livestock Production Systems; Arid, Semiarid and Humid.*

*Table 1: Percent area covered by the three livestock production systems across the five counties in the project study area.*

| County | Arid | Semiarid | Humid |
|---|---|---|---|
| Isiolo | 99% | 0% | 1% |
| Meru | 43% | 33% | 24% |
| Nyeri | 0% | 57% | 43% |
| Samburu | 83% | 3% | 14% |
| Laikipia | 5% | 2% | 93% |

## Land Use Land Cover Change

In 2000, the dominant land use land cover (LULC) was grassland which accounted for 55% of the entire study area. Open shrublands covered the second highest continuous extent at 22% of the total area. As a combination, the remaining fourteen LULC types covered less than 25% of the total study area (figure 4a). Major LULC changes occurred within the two dominant LULC types. Area covered by open shrublands decreased consecutively by 2.79% and 12.05% in the year 2010 and 2020 respectively. Open shrublands cover is still expected to decrease further by 6.01% by the year 2030. On the other hand, area covered by grassland increased by 8.63% in 2010 and 11.91% in 2020 and is expected to increase by 10.31% by the year 2030 (figure 4).

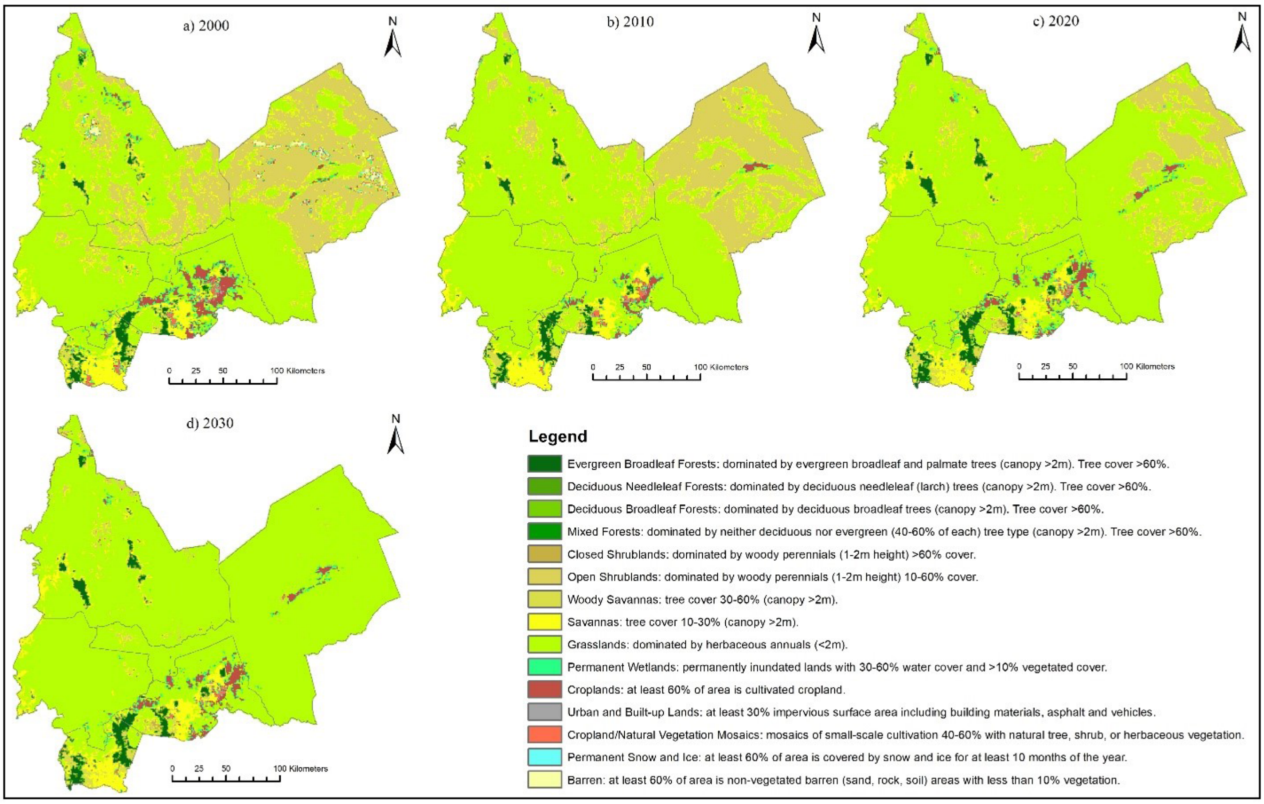


*Figure 4:LULC in the ENNCA region 2000-2030*

## Estimated livestock numbers and densities in the ENNCA region

Figure 5 shows the distribution of cattle, shoats and camel densities. Cattle densities are high in the southern part of the study area and have been on the rise since 2000 (figure 5a-c). Cattle densities are projected to decline slightly by 2030 from 2020, as shown by figure 5 d. In absolute numbers, the highest cattle numbers are observed and projected in the humid zone in the period between 2000 and 2030. Laikipia will have the highest number of cattle (318,150) followed by Meru which will have 109,295 in the humid zone. Meru and Nyeri are projected to have considerable number of cattle of 194,980 and 179,258 respectively in the semi-arid zones by 2030. While there is an overall increase in the cattle numbers across all the counties in the study period, Nyeri county will experience the highest percentage increase in cattle density compared to the other counties (Table 3).

Sheep and goats (SHOATS) densities are observed to increase within the study area during the study period (figure 5 c-h). Major increase in shoats' numbers is observed in the arid zones with the numbers reaching 2,582,590 in 2030. Isiolo will have the highest number of shoats of 1,325,388 by 2030 followed by Samburu with 951,921 shoats in the arid zones. It is worth noting Laikipia will have a considerable number of shoats in the humid zone (1,037,646) in 2030. A considerable population of shoats is projected in the semi-arid and humid zones of Meru and Nyeri. While there is an overall increase in shoats densities across all counties, the highest increase will be realized in Isiolo and Nyeri counties.

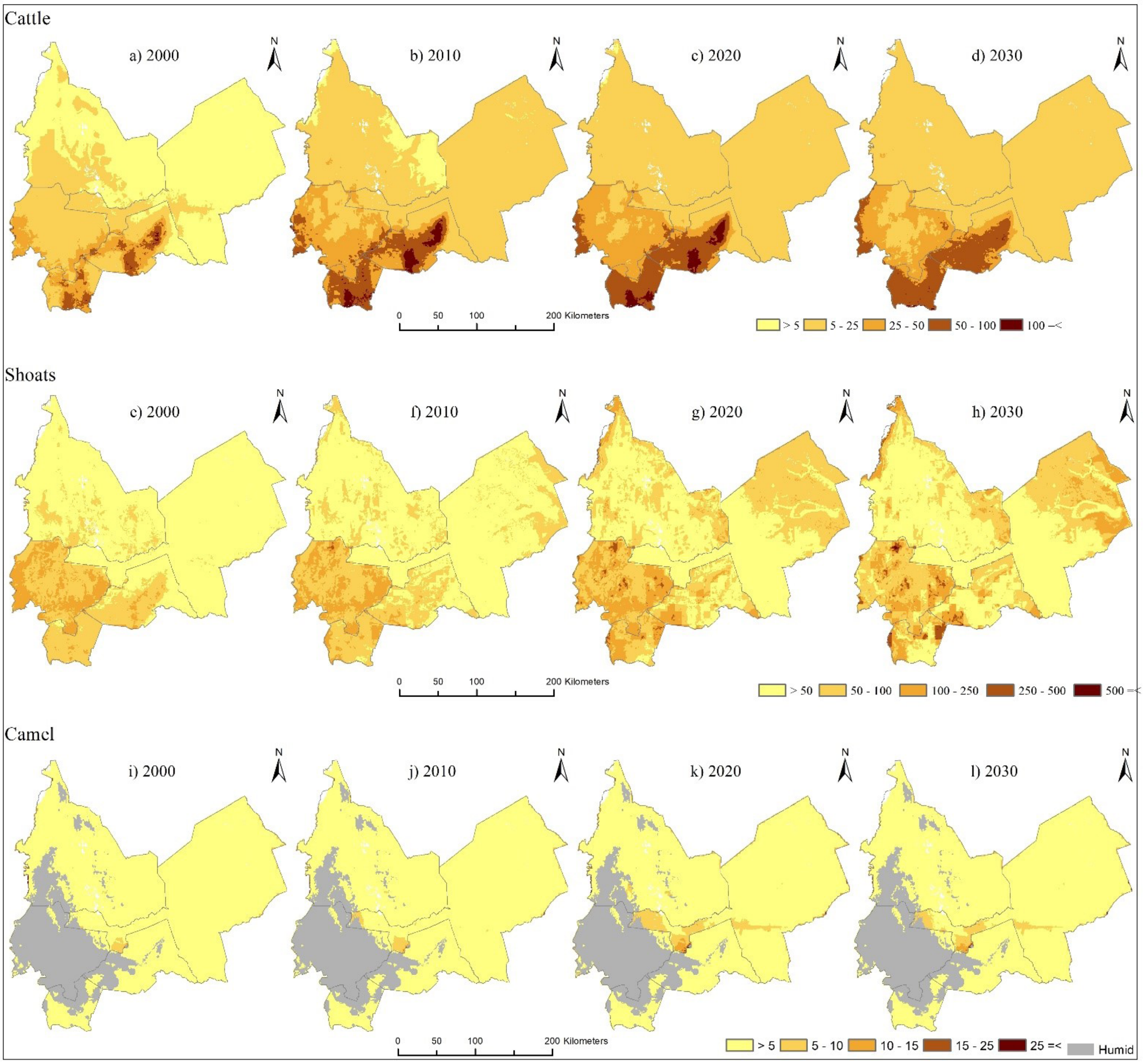


*Figure 5: Livestock Densities Projected to 2030*

Camel densities and numbers have increased across the study area during the study period (figure 5 i-l). Isiolo has the highest camel densities from the year 2000 to 2020. The high densities in Isiolo are expected to persist in 2030. In absolute numbers highest number of camels are observed in the arid zone (104,584) in the period between 2000 and 2030. In 2030, Isiolo will have the highest camel numbers (74,991), followed by Samburu (27,960). Laikipia will have the highest number of camels in the humid zone (13,423) while Samburu and Meru are projected to have some considerable camel numbers of 2,144 and 1,872 in the semi-arid zones by 2030. While there is a projected general increase in camel densities across all five counties, the greatest increase in camel densities will be realized in Laikipia and Isiolo counties (figure 5 i-l). Camel distributions were restricted outside the humid zones.

## Tropical Livestock Unit

We computed Tropical Livestock Unit (TLU) densities and per capita (table 2). TLU densities increased from 2000 to 2020. Projected values for 2030 were still higher than 2000 and 2010 but slightly lower than 2020. Nyeri had the highest TLU densities throughout the study period while Isiolo had the lowest. TLU per capita fluctuated throughout the study period across the counties. Isiolo had the highest TLU per capita in the study period.

*Table 2: Tropical Livestock Unit (TLU) densities(TLU/ha) and per capita TLU (TLU/person) across five counties in the ENNCA study area*

| County | Year | Cattle | Shoats | Camel | Area of county (ha) | TLU density (TLU/ha) | Popula-tion | TLU per capita |
|---|---|---|---|---|---|---|---|---|
| Isiolo | 2000 | 112,289 | 838,382 | 47,655 | 2,538,254 | 0.10 | 129,387 | 1.99 |
| | 2010 | 210,713 | 970,293 | 56,357 | | 0.15 | 143,294 | 2.66 |
| | 2020 | 231,360 | 1,295,687 | 87,779 | | 0.19 | 294,104 | 1.62 |
| | 2030 | 224,099 | 1,327,298 | 76,921 | | 0.18 | 368,938 | 1.24 |
| Laikipia | 2000 | 200,625 | 1,102,813 | 7,952 | 954,402 | 0.34 | 261,144 | 1.23 |
| | 2010 | 358,726 | 1,106,609 | 10,095 | | 0.51 | 399,227 | 1.21 |
| | 2020 | 372,830 | 1,277,329 | 17,238 | | 0.55 | 528,509 | 0.99 |
| | 2030 | 345,096 | 1,147,799 | 14,438 | | 0.50 | 639,451 | 0.75 |
| Meru | 2000 | 218,237 | 446,379 | 3,832 | 699,037 | 0.38 | 1,238,888 | 0.22 |
| | 2010 | 391,668 | 453,355 | 4,383 | | 0.63 | 1,356,301 | 0.33 |
| | 2020 | 413,969 | 533,950 | 6,196 | | 0.68 | 1,565,421 | 0.30 |
| | 2030 | 390,780 | 498,953 | 3,871 | | 0.64 | 1,765,151 | 0.25 |
| Nyeri | 2000 | 132,723 | 281,522 | 145 | 333,620 | 0.48 | 554,970 | 0.29 |
| | 2010 | 250,886 | 308,676 | 157 | | 0.85 | 693,558 | 0.41 |
| | 2020 | 279,884 | 394,648 | 221 | | 0.96 | 809,599 | 0.39 |
| | 2030 | 277,624 | 397,744 | 152 | | 0.95 | 894,578 | 0.36 |
| Samburu | 2000 | 111,684 | 924,052 | 34,403 | 2,102,273 | 0.12 | 203,768 | 1.22 |
| | 2010 | 210,317 | 974,471 | 35,805 | | 0.17 | 223,947 | 1.58 |
| | 2020 | 231,758 | 1,183,845 | 49,539 | | 0.20 | 320,308 | 1.29 |
| | 2030 | 224,381 | 1,109,638 | 37,561 | | 0.18 | 419,849 | 0.92 |

## Total annual meat and milk production in the ENNCA

Cattle milk production has seen increasing in production since 2000 (see table 3) mainly from the humid zones. However, a slight decline is expected by the year 2030. . Cattle meat production has also increased progressively in the ENNCA region from 2000 and is projected to continue increasing to 2020. The greatest increase in cattle meat production is being realized in the arid and semi-arid zones with meat production doubling after every decade. .

Shoats milk production has been increasing and is projected to continue to increase across the counties, mainly from the arid zones. Shoats milk production was not computed in the humid zones. Shoats' meat production has also been on the rise in the last 20 years. This is projected to decline slightly by 2030. Laikipia County will remain the largest shoat meat producer in the region and the leader in shoats milk production (table 3).

Camel meat production was not computed in this study. Camel milk production on the other hand has increased significantly from 2000. Our study project that the milk production will decline slightly by 2030. Arid areas dominate the camel milk production in the area (table 3).

| **Milk Production (Kg) (000s)** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cattle** | | | | **Shoats** | | | | **Camel** | | | |
| Livestock Production Systems | 2000 | 2010 (% Change) | 2020 (% Change) | 2030 (% Change) | 2000 | 2010 (% Change) | 2020 (% Change) | 2030 (% Change) | 2000 | 2010 (% Change) | 2020 (% Change) | 2030 (% Change) |
| Arid | 29,012 | 56,176 (94%) | 130,190 (132%) | 136,886 (5%) | 47,882 | 54,872 (15%) | 70,383 (28%) | 80,577 (14%) | 16,761 | 19,001 (13%) | 28,518 (50%) | 24,027 (-16%) |
| Semiarid | 27,561 | 50,994 (85%) | 112,703 (121%) | 112,755 (0%) | 12,045 | 11,163 (-7%) | 12,279 (10%) | 11,681 (-5%) | 1,012 | 1,093 (8%) | 1,578 (44%) | 1,032 (-35%) |
| Humid | 196,185 | 344,934 (76%) | 779,378 (126%) | 725,657 (-7%) | - | - | - | - | - | - | - | - |
| Counties | | | | | | | | | | | | |
| Isiolo | 16,378 | 30,364 (85%) | 68,065 (124%) | 67,578 (-1%) | 22,869 | 26,664 (17%) | 35,683 (34%) | 41,353 (16%) | 10,661 | 12,611 (18%) | 19,664 (56%) | 17,242 (-12%) |
| Laikipia | 109,469 | 194,624 (78%) | 441,493 (127%) | 407,047 (-8%) | 2,107 | 2,369 (12%) | 2,977 (26%) | 3,437 (15%) | 139 | 168 (21%) | 288 (71%) | 233 (-19%) |
| Meru | 57,107 | 101,232 (77%) | 226,654 (124%) | 216,711 (-4%) | 9,054 | 9,238 (2%) | 10,399 (13%) | 10,909 (5%) | 654 | 745 (14%) | 1,057 (42%) | 661 (-37%) |
| Nyeri | 42,074 | 75,748 (80%) | 173,012 (128%) | 173,753 (0%) | 4,599 | 4,829 (5%) | 5,668 (17%) | 5,971 (5%) | 12 | 12 (-5%) | 14 (25%) | 8 (-47%) |
| Samburu | 27,730 | 50,136 (81%) | 113,047 (125%) | 110,210 (-3%) | 21,299 | 22,934 (8%) | 27,935 (22%) | 30,588 (9%) | 6,307 | 6,558 (4%) | 9,072 (38%) | 6,916 (-24%) |
| ***Meat Production (Kg) (000s)*** | | | | | | | | | | | | |
| Livestock Production Systems | | | | | | | | | | | | |
| Arid | 1,681 | 3,254 (94%) | 7,893 (143%) | 16,889 (114%) | 520 | 596 (15%) | 1,148 (92%) | 1,162 (1%) | - | - | - | - |
| Semiarid | 1,597 | 2,954 (85%) | 6,833 (131%) | 15,272 (124%) | 131 | 121 (-7%) | 200 (65%) | 168 (-16%) | - | - | - | - |
| Humid | 6,720 | 11,814 (76%) | 13,192 (12%) | 19,266 (46%) | 5,119 | 5,115 (0%) | 8,621 (69%) | 7,775 (-10%) | - | - | - | - |
| Counties | | | | | | | | | | | | |
| Isiolo | 898 | 1,675 (87%) | 3,780 (126%) | 7,802 (106%) | 284 | 305 (7%) | 596 (96%) | 606 (2%) | - | - | - | - |
| Laikipia | 3,784 | 6,735 (78%) | 7,787 (16%) | 11,586 (49%) | 3,718 | 3,701 (0%) | 6,013 (62%) | 5,342 (-11%) | - | - | - | - |
| Meru | 2,432 | 4,331 (78%) | 7,299 (69%) | 14,115 (93%) | 524 | 528 (1%) | 971 (84%) | 919 (-5%) | - | - | - | - |
| Nyeri | 1,679 | 3,070 (83%) | 5,036 (64%) | 10,136 (101%) | 464 | 534 (15%) | 1,058 (98%) | 1,139 (8%) | - | - | - | - |
| Samburu | 1,204 | 2,211 (84%) | 4,016 (82%) | 7,788 (94%) | 780 | 766 (-2%) | 1,331 (74%) | 1,100 (-17%) | - | - | - | - |

*Table 3: Milk and meat production in Kg (000s)*

## Livestock water footprint in the ENNCA

Cattle milk water footprint was projected to fluctuate in the three production zones (figure 9). The biggest increase in cattle milk water footprint is projected in the humid zone. Nyeri county is projected to experience the highest increase in cattle water footprint by 2030 (figure 6 a-d).

The projection for cattle meat water footprint between 2000 and 2030 indicated an increase in the arid, semi-arid and humid zones. However, the highest increase in cattle water footprint will be realized in the arid zone while the humid zone will realize the least increase in water footprint (figure 10).

Isiolo and Samburu will experience the highest increase in cattle meat water footprint while Nyeri, Meru and Laikipia counties will experience the least increase in cattle meat water footprint (figure 6 e-h).

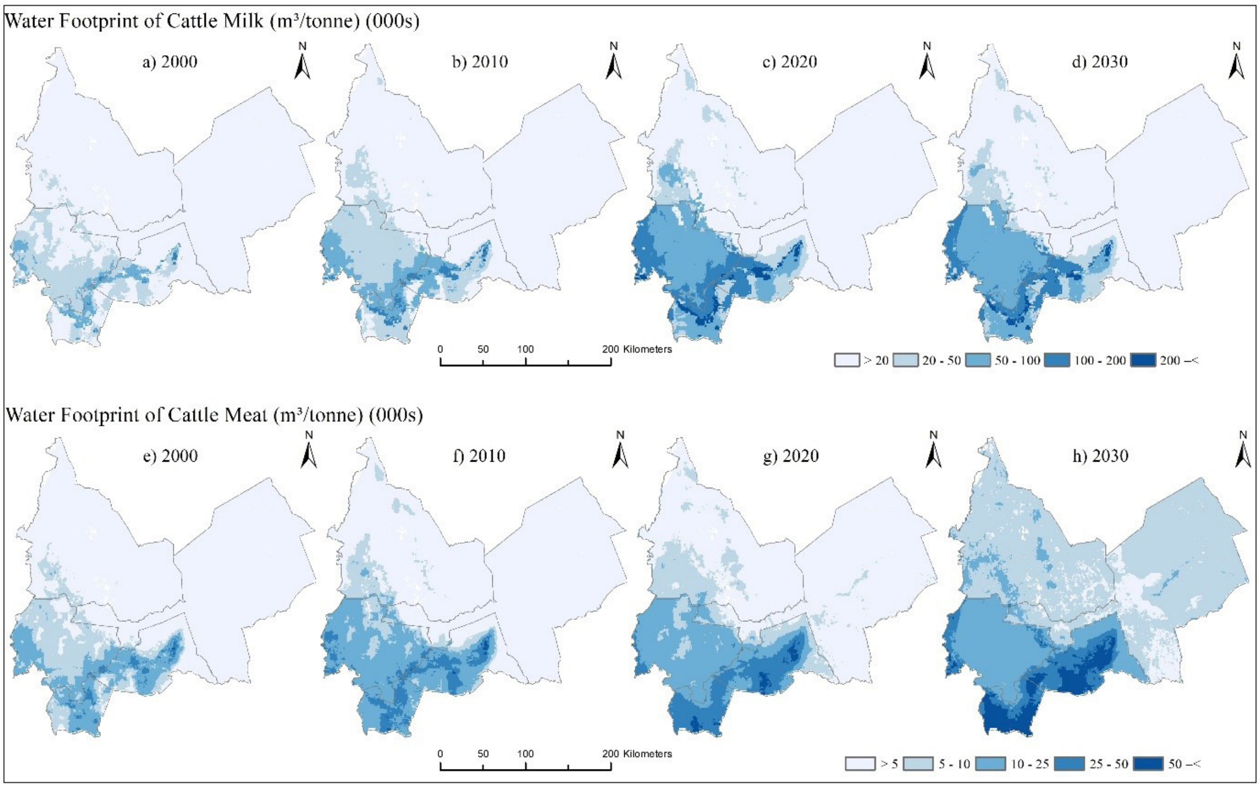


*Figure 6: Cattle water footprint projected to 2030*

Shoats milk water footprint was projected to fluctuate in the three production zones over the period between 2000 and 2030. The arid zone was projected to have the highest milk water footprint (figure 9). Indeed, Isiolo is the only county that will experience the largest increase in shoats milk water footprint. On the contrary, Meru, Nyeri, Samburu, and Laikipia counties will experience a decline in shoats milk water footprint (figure 7 a-d)

Shoats' meat water footprint increased over the period (figure 7). The humid region was projected to have the highest overall water footprint and increase in water footprint over the study period (figure 10). While there is a projected overall increase in shoats meat water footprint across the five counties, the highest increase will be realized in Nyeri, Isiolo and Meru counties (figure 7 e-h).

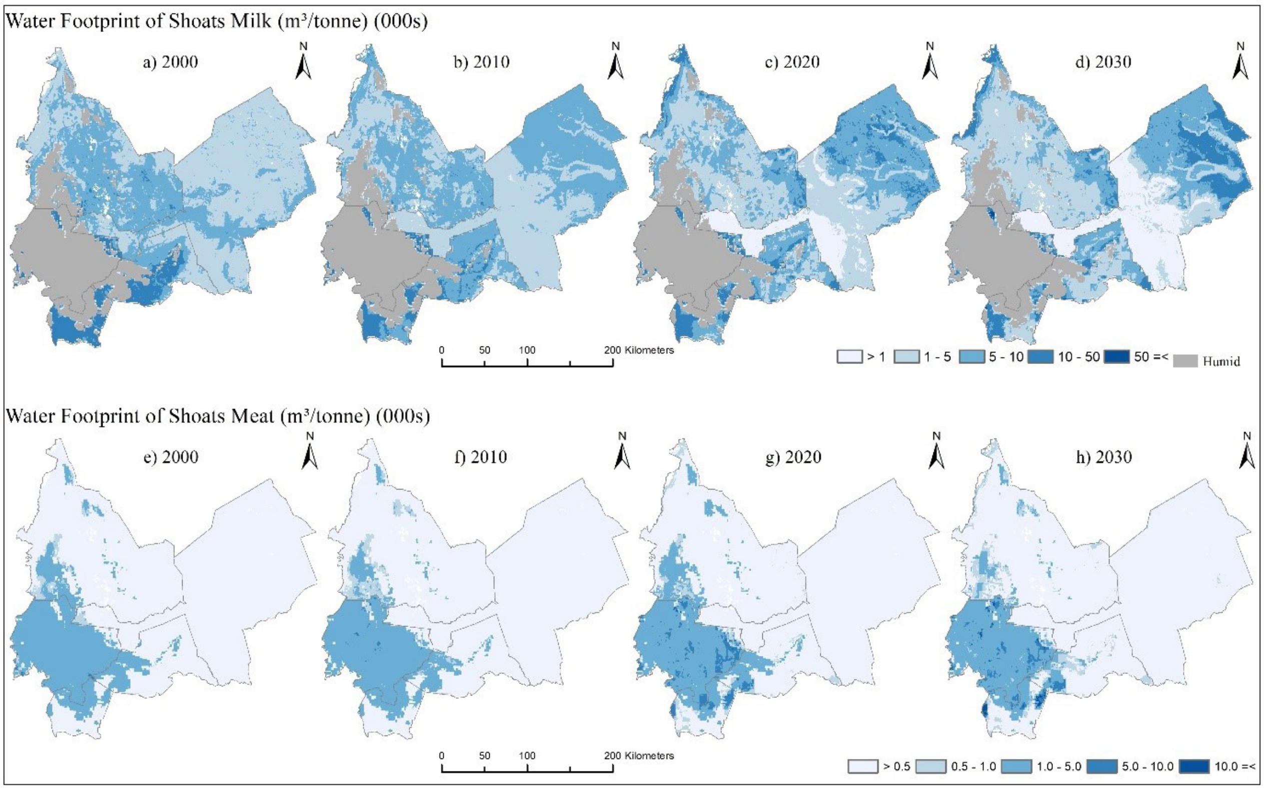


*Figure 7: Shoats water footprint projected to 2030*

Camel milk water footprint increased over the study period. The arid zone is however projected to have the highest camel milk water footprint overall and the highest increase in water footprint over the study period (figure 9). Laikipia and Isiolo will experience the highest increase in camel milk water footprint in the period between 2000 and 2030 (figure 8).

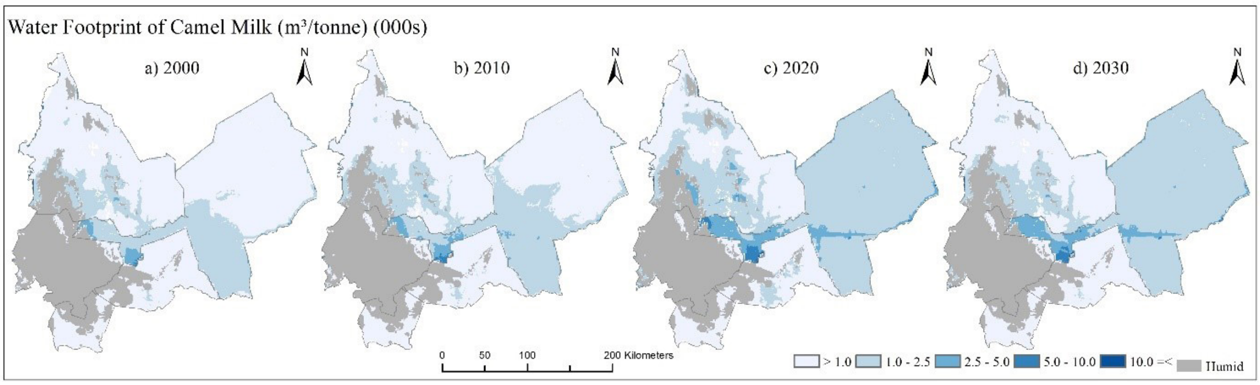


*Figure 8: Camel water footprint projected to 2030*

# DISCUSSION

The projection indicates a consistent increase in grassland in the ENNCA region and an overall gain in cropland across the ENNCA region within the study period which translates to the projected overall increase in livestock production as well as an elevated water foot print related to livestock production.

There is indication for increase in cattle density in all five counties of the ENNCA region with Nyeri experiencing the largest increase in cattle density compared to the other counties. Overall, there will be an increase in livestock densities across the arid, semi-arid, and humid zones but the highest cattle densities will be in the humid zone. Increased cattle densities will translate to an increase in cattle meat production between 2000 and 2030 and effectively an elevated water footprint for cattle meat production. The greatest increase in cattle meat productivity will be realized in the humid zone matching the highest increase in cattle density. However, despite the greatest increase in cattle densities, the humid zone will experience the least increase in cattle meat water foot print compared to the arid and semi-arid zones. In the humid zones, Nyeri will experience the highest cattle meat water foot print which corresponds to a great increase in cattle densities in the study period. The relatively low cattle meat water foot print in the humid zone could be explained by the more intensive production systems characterized by cross-bred cattle with greater feed conversion efficiency and utilization of crop residues for feed (AU-IBAR 2019; Bosire et al. 2019). This is in contrast to the arid and semi-arid production systems with a higher cattle meat water foot print which could be explained by relatively lower efficiency in feed conversion characteristic of the indigenous cattle breeds(AU-IBAR 2019). In addition, indigenous cattle have a high mobility due distance between grazing locations and their habitat (Bosire et al. 2022). In the context of already existing water scarcity in the arid and semi-arid zones and the projected increase in cattle meat water foot print, it is more ideal to focus increase in cattle meat production in the humid zones, which demonstrate a greater water efficiency in cattle meat production in the ENNCA region. The elevated water footprint for cattle meat in the arid and semi-arid zones could also be addressed by utilisation of crop residues from regions such as Meru County which will experience an increase in crop production over the period to 2030.

Cattle milk is also projected to increase in the ENNCA region over the study period, with the highest increase projected in the humid zone. Matching the increase in cattle milk production, cattle milk water foot print is also projected to increase in the arid, semi-arid and humid zones with the greatest increase projected in the humid zones. The humid zone will however experience a sharp decline in cattle milk water foot print between 2020 and 2030. Nyeri county will realize the greatest increase in cattle milk water footprint in the humid zone matching its greatest increase in cattle density. The elevated cattle milk water foot print could be explained by intensive dairy production of cross bred cows in the humid zones (AU-IBAR 2019). Which ischaracterized by utilization of feed concentrates, sub-optimal feed conversion efficiency among cattle, and increased water use in production of fodder crops (Bosire et al. 2019, 2022). The elevated water footprint could be addressed by improving feed use efficiency in cattle through better animal management, acquisition of cattle breeds that are efficient in feed conversion, or utilisation of crop residues which have less water footprint compared to feed concentrates (Ibidhi and Ben Salem 2020). The crop residue and grain for concentrate feeds could be obtained from Meru County, where an increase in crop production between 2020 and 2030 is projected.

There is a projected consistent increase in shoats in the ENNCA region but the biggest increase is expected in Isiolo and Nyeri counties. However, the highest absolute numbers of shoats will be in the arid zone of the ENNCA region. The increase in shoats' densities will be accompanied by a matching increase in shoats' meat predominantly in Laikipia, Nyeri, and Meru counties. Subsequently, an increase in shoats' meat water foot print is projected predominantly in the humid zones compared to the arid and semi-arid zones where it will be lower. It will therefore be feasible to maintain shoat meat production in the arid and semi-arid zones of the ENNCA region which are water efficient in shoat meat production. On the other hand, introduction of more efficient breeds of shoats, improved animal management practices to improve feed conversion efficiency and utilisation of crop residues from regions such as Meru, which are projected to gain in cropland could be adopted to address the increasing shoat meat water footprint in the humid zones.

Shoats' milk production on the other hand is projected to increase in Isiolo, Nyeri, Meru, and Samburu counties between 2000 and 2030, matching the projected increase in shoats' densities in Isiolo and Nyeri counties. The increase in shoats' densities and milk production in Isiolo county will be accompanied by a high shoats milk water footprint. This is reflected by the arid zones' highest shoats' milk water foot print. This is in contrast to a decline in shoats milk water foot print in the semi-arid zone. The results could be explained by the fact that the increase in shoats milk production in the arid zone is driven by increased herd sizes adding to water consumption. The high shoats milk water foot print could be addressed by introduction of water efficient shoats breeds and use of crop residues from regions that will experience increased crop production. On the other hand, the water efficiency in shoats milk production in the semi-arid zones could be explained by adoption of improved shoats breeds and use of crop residues and should be leveraged in enhancing shoats milk production.

Increase in camel densities will be most prevalent in the arid zones of Isiolo and Laikipia counties and it will be accompanied by a consistent decline of open shrub land which constitutes a major dietary component of camels as they are browsers. While camels consume fresh grass, they are predominantly browsers and the availability of woody shrubs is important for their survival. The increase in camel densities in the arid and semi-arid zones will be accompanied by an increase in camel meat and camel milk production in the arid and semi-arid zones in the ENNCA region. Subsequently, the arid zone will experience the highest camel milk water foot print, particularly in Isiolo and Laikipia counties. The elevated camel milk water foot print could be explained by increase in camel densities translating to a direct increase in water consumed (Bosire et al. 2015). The high camel milk water foot print in the arid and semi-arid zones could be addressed by utilization of crop residues from regions that will experience an increase in crop production. Another strategy could be establishment of woody shrubs in the counties of Isiolo, Samburu, and Laikipia where the camel population is expected to increase while the density of the woody shrubs is expected to decline.

## Policy recommendations

- Cattle production is best suited in humid zones while shoats and camels best suited for arid and semi-arid zones. This information should be provided to farmers to inform and optimise decision making in investment in livestock production.
- Extension services should be provided by county governments to support herd management for optimal utilization of feed resources to enhance feed conversion in livestock in the diverse agroecological zones.
- County governments should facilitate smooth exchange in procurement of crop residues across counties to allow utilization of crop residues for animal feeds where most needed.
- County level leadership support in research and adoption of improved livestock breeds to enhance feed conversion efficiency is necessary.

# CONCLUSION

An overall increase in livestock production to support the growing demand for ASFs is projected accompanied by varying changes in water footprint for the three types of livestock. We have based our argument of the suitability of increasing livestock production on the water foot print trends projected for the three categories of livestock.

Humid zones which will have the least increase in water foot print in the ENNCA region will be best suited to support increased cattle meat production. The humid zone will also provide the highest increase in cattle milk production but this will be accompanied by an elevated water foot print which could be explained by feed conversion inefficiencies in the production systems.

Shoats meat water foot print will be lowest in the arid and semi-arid zones and an increase in shoats meat production should be targeted in the two zones. The semi-arid zone on the other hand is the most water efficient in shoat milk production and should be targeted for increased shoat milk production.

The semi-arid zones will be more water use efficient in camel milk production compared to the arid zones and therefore should be targeted for increased camel milk production.

Water use inefficiencies in the three livestock categories across the three agroecological zones could be addressed by adoption of livestock breeds that are more efficient in feed conversion, utilization of crop residues, and better herd management to enhance feed conversion.

# REFERENCES


AU-IBAR. 2019. "Kenya Livestock Breeds Catalogue."

Bac, Dorin, Alina Badulescu, and Eszter Lang. 2011. "Excesses and Challenges of the Economic Growth. A Brief History: From Malthus to Al Gore." Actual Problems of Economics 117(3).

Bhagat, Sudheer, Anupam Soni, Gajendra Yadav, Ak Santra, Sharad Mishra, VN Khune, Ashutosh Dubey, Aayush Yadav, and Sweta Banjare. 2020. "The Water Footprint of Livestock Production System and Livestock Products: A Dark Area: A Review." ~ 83 ~ International Journal of Fauna and Biological Studies 7(1):83–88.

Blackburn, Harvey. 2003. "Livestock - Environment Interactions." (April):88.

Bosire, Caroline K., Nadhem Mtimet, Dolapo Enahoro, Joseph O. Ogutu, Maarten S. Krol, Jan de Leeuw, Nicholas Ndiwa, and Arjen Y. Hoekstra. 2022. "Livestock Water and Land Productivity in Kenya and Their Implications for Future Resource Use." Heliyon 8(3):e09006. doi: 10.1016/j.heliyon.2022.e09006.

Bosire, Caroline K., Joseph O. Ogutu, Mohammed Y. Said, Maarten S. Krol, Jan de Leeuw, and Arjen Y. Hoekstra. 2015. "Trends and Spatial Variation in Water and Land Footprints of Meat and Milk Production Systems in Kenya." Agriculture, Ecosystems and Environment 205. doi: 10.1016/j.agee.2015.02.015.

Bosire, Caroline K., J. Rao, Voster Muchenje, Mark Van Wijk, Joseph O. Ogutu, Mesfin M. Mekonnen, Joseph Auma, Ben Lukuyu, and J. Hammond. 2019. "Adaptation Opportunities for Smallholder Dairy Farmers Facing Resource Scarcity: Integrated Livestock, Water and Land Management." Agriculture, Ecosystems and Environment 284. doi: 10.1016/j.agee.2019.106592.

Bouwman, A. F., K. W. Van Der Hoek, B. Eickhout, and I. Soenario. 2005. "Exploring Changes in World Ruminant Production Systems." Agricultural Systems 84(2):121–53. doi: 10.1016/J.AGSY.2004.05.006.

Chapagain, A. K., and A. Y. Hoekstra. 2003. "Value of Water Research Report Series No. 13." (13).

Chapagain, Ashok K., and Arjen Y. Hoekstra. 2008. "The Global Component of Freshwater Demand and Supply: An Assessment of Virtual Water Flows between Nations as a Result of Trade in Agricultural and Industrial Products." Water International 33(1). doi: 10.1080/02508060801927812.

Chertow, Marian R. 2000. "The IPAT Equation and Its Variants." Journal of Industrial Ecology 4(4). doi: 10.1162/10881980052541927.

Galli, Alessandro, Thomas Wiedmann, Ertug Ercin, Doris Knoblauch, Brad Ewing, and Stefan Giljum. 2012. "Integrating Ecological, Carbon and Water Footprint into a 'Footprint Family' of Indicators: Definition and Role in Tracking Human Pressure on the Planet." Ecological Indicators 16:100–112. doi: 10.1016/J.ECOLIND.2011.06.017.

Gerbens-Leenes, Winnie, Arjen Y. Hoekstra, and Theo H. Van Der Meer. 2009. "The Water Footprint of Bioenergy." Proceedings of the National Academy of Sciences of the United States of America 106(25):10219–23. doi: 10.1073/pnas.0812619106.

Heinke, Jens, Mats Lannerstad, Dieter Gerten, Petr Havlík, Mario Herrero, An Maria Omer Notenbaert, Holger Hoff, and Christoph Müller. 2020. "Water Use in Global Livestock Production—Opportunities and Constraints for Increasing Water Productivity." Water Resources Research 56(12). doi: 10.1029/2019WR026995.

Hoekstra, Arjen Y., Ashok K. Chapagain, and Pieter R. van Oel. 2019. Progress in Water Footprint Assessment: Towards Collective Action in Water Governance. Vol. 11.

Ibidhi, R., and H. Ben Salem. 2020. "Water Footprint of Livestock Products and Production Systems: A Review." Animal Production Science 60(11):1369–80. doi: 10.1071/AN17705.

King, John M. 1983. "Livestock Water Needs in Pastoral Africa in Relation to Climate and Forage." International Livestock Centre For Africa (September).

Latino, Lucia Rita, Ugo Pica-Ciamarra, and Dominik Wisser. 2020. "Africa: The Livestock Revolution Urbanizes." Global Food Security 26(June):100399. doi: 10.1016/j.gfs.2020.100399.

Mekonnen, M. .., and A. Y. Hoekstra. 2010. "A Global and High-Resolution Assessment of the Green, Blue and Grey Water Footprint of Wheat." Hydrology and Earth System Sciences 14(7). doi: 10.5194/hess-14-1259-2010.

Mekonnen, M. M., and A. .. Hoekstra. 2010. "The Green, Blue and Grey Water Footprint of Farm Animals and Animal Products. Volume 1: Main Report." Unesco Value of Water Research Report Series No. 48.

Mekonnen, M. M., and A. Y. Hoekstra. 2011. "The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products." Hydrology and Earth System Sciences 15(5). doi: 10.5194/hess-15-1577-2011.

Mekonnen, Mesfin M., and Arjen Y. Hoekstra. 2012. "A Global Assessment of the Water Footprint of Farm Animal

Products." Ecosystems 15(3):401–15. doi: 10.1007/s10021-011-9517-8.

Ngigi, Margaret. 2011. "The Case of Smallholder Dairying in Eastern Africa." SSRN Electronic Journal. doi: 10.2139/ssrn.695481.

Rege, J. E. O., A. Kahi, M. Okomo-Adhiambo, J. Mwacharo, and O. Hanotte. 2001. Zebu Cattle of Kenya: Uses, Performance, Farmer Preferences and Measures of Genetic Diversity.

Staal, S. J., M. Owango, H. Muriuki, M. Kenyanjui, B. Lukuyu, L. Njoroge, D. Njubi, I. Baltenweck, F. Musembi, O. Bwana, K. Muriuki, G. Gichungu, a Omore, and W. Thorpe. 2001. "Greater Nairobi Milk Shed." Development - SDP Research Report (November).

Stroosnijder, Leo, Demie Moore, Abdulaziz Alharbi, Eli Argaman, Birhanu Biazin, and Erik van den Elsen. 2012. "Improving Water Use Efficiency in Drylands." Current Opinion in Environmen