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Carrying Capacity and Stocking Rate of Grazing Areas of Arsi Mountain National Park, Ethiopia

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Abstract

Arsi Mountain National Park, one of the protected areas in Ethiopia, is under a serious threat from livestock grazing disturbances. Basic information on the carrying capacity of available grazing land and livestock grazing pressure is needed to make management decisions for addressing livestock grazing-related disturbances. This study addresses this caveat and assessed the carrying capacity, stocking rate, and socio-economic factors driving local communities to graze their livestock in the park. Galama Mountain of Arsi Mountain National Park and four districts surrounding Galama Mountain were purposively selected for this study. Three categories of data: 1) ecological data, 2) geospatial data, and 3) socio-economic data were collected, and analyzed. Total dry matter production of Tena, Sherka, Lemu Belbelu, and Degalu Tejo districts was 171807, 188573, 148966, and 144305 tonnes, respectively. The result shows the mean carrying capacity of grazing land in the study area was 0.32 TLU/ha/year (3.37 ha/TLU/Year). The mean carrying capacity of Tena, Sherka, Lemu Belbelu, and Degalu Tejo districts, and Galama mountain were 0.28 TLU/ha/year (2.64 ha/TLU/Year), 0.38 TLU/ha/year (2.66 ha/TLU/Year), 0.17 TLU/ha/year (5.94 ha/TLU/Year), 0.28 TLU/ha/year (3.56 ha/TLU/Year), and 0.25 TLU/ha/year (1.02 ha/TLU/Year), respectively. The mean stocking rate of Tena, Sherka, Lemu Belbelo, and Degalu Tejo districts were 0.04, 0.15, 0.15, 1.12, and 0.37 TLU/ha, respectively. Annual feed availability is estimated at 653,651 tons against the requirement of 2,134,171 tons, resulting in a deficit of 69.4% annually. A significant relationship exists between explanatory variables and grazing livestock in the park. Age, livestock number, and education made a statistically significant contribution toward predicting grazing livestock in the park. Gender, household size, and source of income were not statistically significant but showed both positive and negative associations with grazing livestock in the park. Overall, the livestock stocking rate is by far greater than the sustainable carrying capacity and available feed is less than half of the recommended annual feed demand. Overstocking and feed deficit in the surrounding districts are thus very serious problems for the park. Hence, appropriate grazing pressure reduction strategy and grazing land improvement action are required to protect the biodiversity and ecosystem services that the park provides. The key factors bringing about a variation in park dependency for their livestock feed can be considered and factored into planning, designing, and implementing programs and activities for park sustainability.

Keywords: Arsi Mountain, carrying capacity, grazing pressure, National Park, Ethiopia

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1. Introduction

The creation of protected areas, such as National Parks, has globally been considered as the principal strategy for biodiversity conservation, climate change mitigation, and adaptation. As a result, the number and size of protected areas have been showing increasing trends worldwide. Despite such heavy reliance on protected areas as a conservation strategy and the increasing trends in their number and coverage, many protected areas are in danger of not achieving the specific conservation goals for which they were created (Bernard et al., 2014). Increased anthropogenic disturbance is among the major challenges to achieving the conservation goals of protected areas (Asefa et al., 2016; Ayalew et al., 2019; Bernard et al., 2014; Girma et al., 2018).

Currently, the loss of biodiversity has become a major global environmental concern because it does not entail only loss of species, but also entails disruption of ecosystem processes and loss of the ecosystem services and benefits they provide to human beings (Muluneh, 2021). Unless effective conservation measures are in place, the future existence of biodiversity in such protected areas, particularly those of developing tropical countries like Ethiopia, is therefore under question. The first important information needed to develop effective conservation strategies for such protected areas is having basic information on the threats to the ecosystems and their impact on the resources that may require protection. This information aids decision-makers, and conservation agencies understand the threats and their impacts, prioritizing threats accordingly, and clearly defining and implementing effective management actions (Bernard et al., 2014; Diriba et al., 2020). Currently, such basic information is not available for most protected areas, especially in African countries such as Ethiopia.

Ethiopia is among the African countries hosting a high diversity and endemism of plant and animal species. The country is known to contain, among others, 6,500 species of plants (with 600 endemic species), 320 species of mammals (55 are endemic), and 918 species of birds (18 endemic) (Rabira et al., 2015). Among the key measures taken by successive Ethiopian governments to conserve the declining populations of species, have been establishing protected areas such as National Parks, Wildlife Sanctuaries, and Wildlife Reserves. Currently, the country has established 73 protected areas of different categories, including 25 National Parks (Mekbeb et al., 2019). However, like the case of many African countries, the anthropogenic disturbance has generated a significant loss of biodiversity, and grazing by domestic herbivores is a contributing disturbance (Girma et al., 2018; Girma, Worku et al., 2021). Furthermore, many of these protected areas also lack basic ecological information, without which it is hardly possible to make decisions and respond to threats affecting species, ecosystems, and the services they provide (Bale Mountain National Park (BMNP), 2017). Therefore, it is a matter of urgency to determine anthropogenic threats and their effects in particular across protected areas where such information is lacking.

In Ethiopia, livestock grazing is an increasing and unmanaged anthropogenic disturbance to biodiversity and ecosystem service of the most protected areas and is considered an immediate priority for action (Girma et al., 2018; Ayalew et al., 2019; Biru et al., 2017; Tesema, 2022). In the areas around protected areas, livestock production is the primary and most widespread activity among local people. The grazing of these animals takes place without any regulation (Asefa et al., 2016; Girma, Chuyong, & Mamo, 2018). Uncontrolled livestock grazing is linked to a variety of threats to wildlife, especially the mountain nyala and Ethiopian wolf. Nyalas and other antelopes compete directly with livestock for food and are usually absent from areas where livestock numbers are high. Increased numbers of livestock are also detrimental to rodent populations, possibly reducing the prey base of the Ethiopian wolves. Maintaining the health and productivity of grazing lands by controlling the livestock stocking rate to remain within carrying capacity is of significance to ensuring sustainable management of grazing lands and other components of an ecosystem (Meshesha et al., 2019; Piipponen et al., 2022).

Studies on the carrying capacity of available grazing lands and livestock stocking rate are needed to provide evidence for deciding suitable sustainable management related to livestock grazing activity. Understanding livestock grazing practices in the ecosystem is a research priority for conservation biologists worldwide (Vial, 2010) and is identified in the strategic plan for Ethiopian wolf conservation (Ethiopian Wildlife Conservation Authority (EWCA), 2017). Despite the importance of analysis of conservation threats related to livestock grazing disturbances for designing tools to help conservationists ameliorate threats of livestock disturbances, there have been only a handful of studies from Ethiopia (Giday et al., 2018; Vial, 2010). Of these studies, only minor attention was paid to determining carrying capacity and grazing pressure in the protected areas of Ethiopia.

The only study cited along this line is that of Vial (2010) and Giday et al. (2018) which assess the livestock grazing pressures and carrying capacity in areas inside the parks. However, it would be meaningless to conduct the study in areas inside the park without considering the areas used by the same animals outside the park. Yet, the determination of the grazing pressure and carrying capacity of an area inside the park and areas used by the same animals outside the parks are lacking. The absence of adequate study prevents timely management and conservation decisions that could help to protect biodiversity and ecosystem services provided by the parks. Thus, having such information is crucial to design tools to help conservationists ameliorate threats (Bauer et al., 2022; Vial, 2010).

Arsi Mountain National Park (AMNP), is one of the national parks in Ethiopia, was established in 2011, to protect the area's unique and threatened biota and for watershed conservation (UNEP-WCMC, 2022). The park is home to 30 species that are both common and Endemic to its ecoregion. Endemic wildlife in the park includes the endangered mountain nyala (*Tragelaphus buxtoni*), Menelik's bushbuck (*Tragelaphus scriptus menelik*), (Girma et al., et al., 2018)and Ethiopian wolf (*Canis simensis*) (Marino & Sillero-Zubiri, 2011). The park is home to several rare and limited-range highland rodents (Kostin et al., 2019). It also consists of 99 bird species under 39 families such as Helmeted Guineafowl, Laughing dove, little bee-eater, and Blackwood hoopoe. Furthermore, Mountain rainfall sustains numerous streams and alpine lakes such as Lake Ziway (Bantihun et al., 2020).

Despite this, the park has been under threat from intense human activity such as excessive livestock grazing, human-caused fires, and wood collection (Girma et al., 2018; Kostin et al., 2019). Such human-induced actions can adversely affect the area's unique and threatened biota. While urgent management actions are needed to abate these threats and mitigate the actual and potential impacts on biodiversity, it is also important to have an understanding of the status of the threats and their impacts on ecosystems. Such understanding would assist managers of the park determine the magnitude of the impacts and take more effective, informed management decisions. However, published basic ecological information on anthropogenic disturbances, including livestock grazing activity, has been lacking. Therefore, this study was conducted to provide basic information on carrying capacity medium and large and livestock stocking rate that would aid decision-making and promote future research. The specific objectives were to estimate the grazing land carrying capacity, and available livestock stocking rate, and to assess socioeconomic factors driving local communities to graze their livestock in the park.

2. Material and Method

2.1. Description of the Study Area

The project was conducted in Ethiopia, Arsi mountain national park, and park adjacent districts of the east Arsi zone (Figure 1). AMNP is located in the southeastern part of Ethiopia in Oromiya Regional State. The park consists of four fragment blocks that are no longer connected, namely, Dera, Chilalo-Galama, Kaka, and Hunkolo. The present study area, Galama Mountains (part of Chilalo-Galama block), is situated between 7.48 to 7.88∘ N and 39.27 to 39.51∘ E and located between the inter boundary regions of four Woredas (Districts), namely, Tena, Degeluna-Tijo, Shirka, and Lemu-Bilbilo (Girma et al., 2018). The study area is characterized by a humid montane climate with a bimodal rainfall pattern. The mean annual rainfall ranges from 778.7 to 1089.65 mm. The study area has a mean monthly maximum temperature of 22.4∘ C and a minimum of 11.1∘ C (ENMA, 2015).

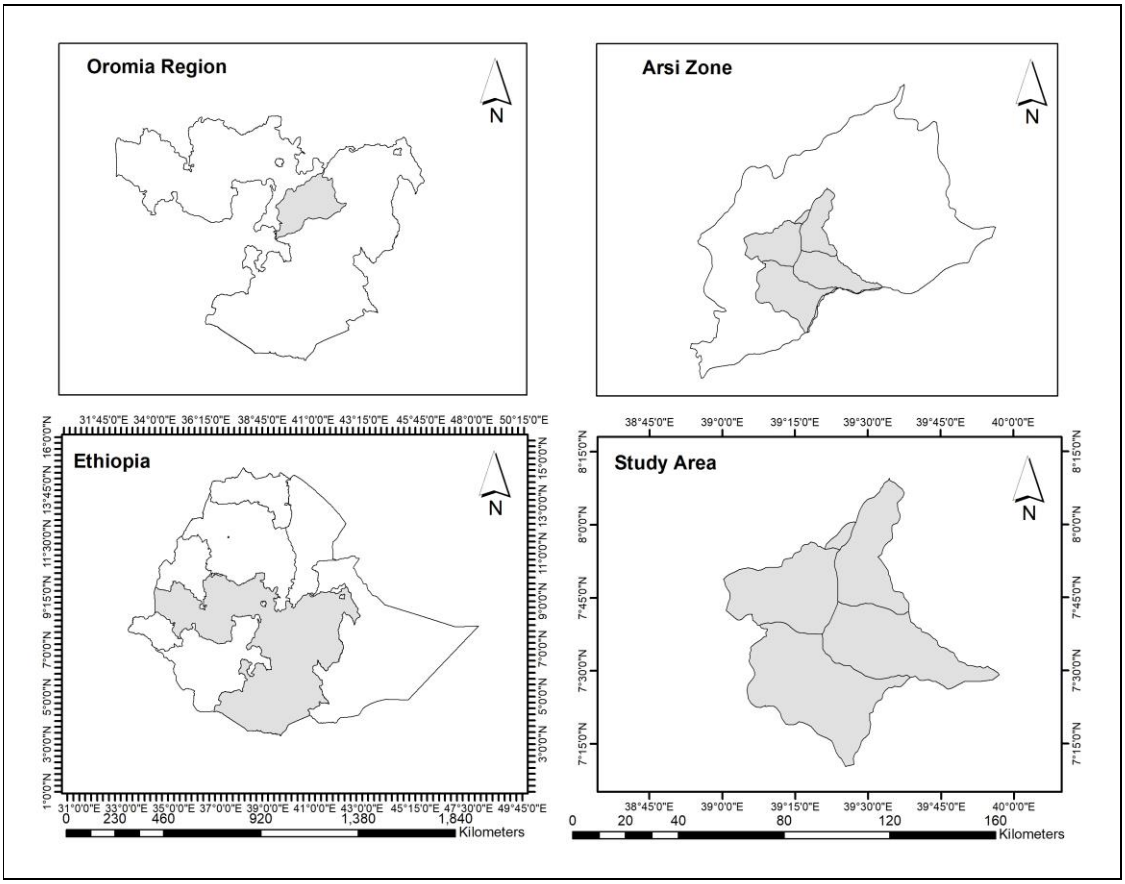


Figure 1: Map of Study Area, Galama Mountain of Arsi Mountain National Park and surrounding districts, Oromia Region, Ethiopia

Galama Mountains are characterized by Afro-alpine vegetation at higher altitudes (3600–4008 m asl), dominant ericaceous vegetation in the middle altitude (3539–3889 m asl), and remnant Afro-montane (2843–3456 m asl) forest (Tena Woreda) and mixed plantations (3181–3340) (Lemu-Bilbilo and Shirka Woredas) at the lower altitudes. The mountains harbor metapopulations of endemic and endangered large mammals like Tragelaphus buxtoni (mountain nyala), Canis simensis (Ethiopian wolf), and Tragelaphus scriptus Menelik (Menelik's bushbuck) (Girma et al., 2018). The districts bordering the Galama blocks are one of the most populous districts in the region, and more than 90% of the population in each district lives in rural areas surrounding the mountains. The park is surrounded by an agriculture-dominated landscape followed by human settlements often influencing the forest landscape with severe human inhabitations and livestock encroachments. Livestock grazing is a common activity in the area for decades that has led to habitat degradation and fragmentation (Girma et al., 2018).

2.2. Methods

2.2.1 Carrying Capacity of Grazing Lands

Determination of carrying capacity used both primary and secondary data sources. Livestock population and land-use land cover-based dry matter production information was collected from various published and unpublished materials and organized for further analysis. Land-use and land cover maps for the year 2022 were developed from satellite images (Landsat 8). The field data were recorded using ground control points and analyzed in ArcGIS 10.4.1 software. The outcome of land-use land cover used for the estimation of biomass (dry matter) production within the study area. Each land-use class in all the districts was assessed from potential green fodder sources. Finally, all available green fodder was converted to DM equivalent using a standard conversion factor (Table 2; (Food and Agriculture Organization of the United Nations (FAO), 2018; Gebeyehu et al., 2021).

The Garmin GPSMAP64 devices were used to collect representative ground truth data for each LULC. About 210 Ground Control Points (GCP) were collected and used as a reference during image interpretation and classification accuracy assessment. In addition to this, livestock population data were collected from the district Livestock and Agriculture and Natural Resource Office. Cloud-free satellite images were downloaded and processed to obtain the land use and land cover map. ArcGIS10.5 software was used to analyze remote sensing data and prepare land use and cover map (Gebeyehu et al., 2021; Meshesha et al., 2019).

Land use land cover-based data dry matter production was used to determine carrying capacity (Food and Agriculture Organization of the United Nations (FAO), 2018; Gebeyehu et al., 2021; Meshesha et al., 2019). The factors used for converting land area in hectares to biomass in tonnes were 1.2, 2, and 2 for forest, grassland, shrubland, wetland, and cropland respectively (Amsalu & Addisu, 2014; Food and Agriculture Organization of the United Nations (FAO), 2018)). For estimating the carrying capacity of the grazing lands of the study area, the concept of tropical livestock unit (TLU) was used. In this case, we used a use factor of 50% (0.5); TLU was taken at 2.5% of the body weight as proposed for Ethiopia by Serunkuma and Olso (1998) and was calculated according to Meshesha et al. (2019) and Fenetahun et al. (2022)

Carrying capacity (ha/TLU/Year) = [D/[$\text{TDM} * \text{UF}]$**]/**R

where, D= number of days in a year, TDM= Total dry matter yield from the area (Kg ha-1), UF= utilization factors (0.5 in our case), R= daily dry matter requirement (Kg/TLU), 2.5% of body weight, which is 6.25 kg per day for one TLU (One TLU is 250 kg grazing animal (Meshesha et al., 2019). The analysis included the number of animals and grazing rangeland areas. And all groups were converted to TLU. The LULC data-based dry matter was converted into kilogram per hectare (kg/ ha), and the proper use factor was taken as 50% to calculate available forage. The biomass production and carrying capacity data were analyzed using a Microsoft Excel program to generate descriptive statistics.

2.2.2 Stocking Rates of Livestock

Similar to carrying capacity, the determination of stocking rate also used both primary and secondary data sources. Livestock population data were collected from the district Agriculture and Natural Resource offices and LULC maps for the year 2022 were developed from satellite images (Landsat 8) and organized for further analysis. Cloud-free satellite images were downloaded and processed to obtain the land use and land cover map. Arc GIS10.5 software was used to analyze remote sensing data and prepare land use and cover map (Gebeyehu et al., 2021; Meshesha et al., 2019).

The stocking rate was estimated from the total livestock population and total grazing land in the study area. Stocking rate is the relationship between the number of animals and the total area of the land in one or more units utilized over a specified time; an animal-to-land relationship over time. The stocking rate is defined as the number of animals on grazing land for a specified period and is usually expressed in TLU ha^{-1} (Habte et al., 2021; Meshasha et al. 2019). The stocking rate is determined using the following formula:

$$\text{Stocking rate for the year (TLU ha}^{-1}\text{ year}^{-1}\text{)} = \text{TLU} \,/\, \text{total grazing area}$$

The livestock population was determined from total livestock numbers in districts of the study area. Before determination of the stocking rate, livestock number of different species was converted to Tropical Livestock Units (TLU; 250 kg = 1 TLU) by taking factors of 0.7, 0.1, 0.1, 0.5, 0.7, and 0.9 for cattle, sheep, goat, donkey, mule, and horse respectively ((Food and Agriculture Organization of the United Nations (FAO), 2018). The total area of grazing land is determined from LULC analysis. Cloud-free satellite images were downloaded and processed to obtain the LULC map of the study areas. Then, hybrid unsupervised and supervised classification was carried out using Arc GIS10.8 software. The livestock population data and stocking rate were analyzed using a Microsoft Excel program to generate descriptive statistics.

2.2.3 Assessment of Socio-economic Factors

The data required to assess the socio-economic factors driving communities to graze their livestock in a park was collected through a structured questionnaire survey of households selected from four districts surrounding Galama Mountain of Arsi mountain national park. In this study, a multistage sampling design was employed to select the study districts, kebeles, and households. In the first stage, four districts surrounding Galama Mountain were purposively selected based on their interaction with Galama Mountain part of the park. The four districts are Tena, Degeluna-Tijo, Shirka, and Lemo Belbelo districts (Girma et al., 2018). In the second stage, thirteen (13) kebeles (3 from Tena, 4 from Degeluna-Tijo, 3 from Shirka, and 2 from Lemmu-Bilbilo districts) were randomly selected. Finally, the number of households from the selected kebeles was proportionally selected for the study. Total households in the study areas i.e., 133,530 households were used to determine sample households (East Arsi Zone Agricultural and Natural Resource Office, 2022). To arrive at the number of households (HHs) to be sampled, the formulae $n = (N/1+N\ (e)^2)$ was applied (Yamane T, 1967) and (Israel, 1992).

Whereas, N= Total household, n= Sample size, and e= Confidence level (at 95%).

where ni = assigned sample size of district, n = Total sample size, Ni = Household size of single district, N= Total household size Sample Size = n = 96,327/1+96,327 $(0.05)^2$

About 398 households were targeted in this study. Following the determination of the total sample size, a proportionate stratified sampling procedure was applied to draw samples in each stratum. The sample size derived from the above formula was proportionately distributed to the five districts using the proportion allocation to size formula by (Nashipay et al., 2022). All sample households were selected using random sampling based on the household registration roster of the target kebeles and the villages. The following formula was used to get the household proportion required for each of the four districts. The sample households were selected by using simple random sampling (lottery method). Lists of households were obtained from respective administrative offices.

$N_h = n\ N_h/N$

Where; nh, is the sample size per district; n, is the total sample size of the study; Nh is the total households per district; N is the total households.

Table 1: Household sample size by districts

Sample Districts	No. of Households	Sample Size
Tena	10,351	Nh =n Nh/N= 53
Degeluna-Tijo	18,231	$N_h = n\ N_h/N$ = 93
Shirka	26,841	Nh =n Nh/N= 137
Lemu Bilbilo	22,455	Nh =n Nh/N= 115
Total	77,878	Nh =n Nh/N= 398

Face-to-face questionnaire surveys were administered to selected households. Households were used as the unit of analysis for the questionnaires because assets are typically held and managed at the family level in the case study area. A combination of closed and open-ended questions was developed and pre-tested before administering it to the intended household heads. The questionnaire was translated into the local language and enumerators, with good knowledge of the local language (Oromifa), were selected to administer the questionnaire, and the data were subsequently translated into English.

The questionnaire is composed of two main sections. Section 1 contained questions covering respondents' demographic and socio-economic background. This included sex, age, education level, household size source of income, and total number of livestock. Below is the description of how the latter variables were operationalized in this study. On the other hand, section 2 of the questionnaire contained questions focusing on grazing livestock in the park.

Data on the various types of livestock feed resources and the level of reliance on park resources for livestock feed were solicited from the respondents. The method of formulating the questionnaire was guided by a literature review (Garekae et al., 2017).

Data was compiled and managed using JMP Pro software version 14.0.0 for Macintosh (SAS Institute, Cary, NC, USA). Descriptive statistics in the form of frequencies, proportions, measures of central tendency, and dispersion were used to summarize the socioeconomic and demographic data. Logistic regression analysis was used to test for socioeconomic factors' predictive ability on livestock grazing in the park. In this study, the outcome variable (livestock grazing in the park) was regressed against selected explanatory variables: sex, age, education level, household size source of income, employment, and number of livestock. These variables were used as a proxy for socioeconomic. The variables were chosen mainly because they cut across the social and economic domains; hence, they will provide a comprehensive insight into the pattern of household livestock grazing in the park.

The outcome variable livestock grazing in the park was measured as a dichotomous response occupying the value of 1 or 0, where 1 denotes livestock grazing in the park while 0 means not grazing livestock in the park. The binary logistic regression model was used to determine the socioeconomic factors influencing households’ livestock grazing in the park. Since there is no set conventional cut-off point for classifying livestock grazing in the park, the average value across the study areas was considered as the threshold for categorizing livestock grazing in the park into two levels: grazing in the park and not grazing in the park. This approach has been widely used in natural resources management and biodiversity conservation literature (Garekae et al., 2017). Table 2 presents the description and measurement of the explanatory variables used in the logit model.

Table 2: The description of the explanatory variables used in the logit model

Variables	**Explanation**	**Expected sign**
Age	Age of household head in years	Positive
Household size	Number of family members in the household	Positive
Sex	1 if male, 0 if female	Positive
Education	Household head level of education (0 = none, 1 = Read and write, 2 = primary, 3 = secondary)	Negative
Source of income	Household source of income (0 = Livestock and livestock products, 1= Crop and livestock production, 2= Crop production, and 4= others)	Negative
Household livestock size	Number of livestock managed by the household	Positive

3. Results and Discussions

3.1 Carrying capacity of grazing lands

For the estimation of carrying capacity, the land use land cover data-based biomass production was used. Figure 1 presents seven identified broad LULC classes in the study area. These are cropland (49.5%), bare land (17.32%), grassland (10.23%), shrubland (9.2%), wetland (5.84), settlement (4.87%) and forest (3.12%) (Table 1). Overall, the results of this study were in line with the previously reported results in Arsi Mountain of Ethiopia and beyond (Belay et al., 2022; Jacob et al., 2017; Kidane et al., 2012) who demonstrated the above-mentioned LULC types in Mountain areas of Ethiopia.

Table 3: Land-use land cover data based on dry matter (DM) production estimation

LULC Types (2022)	**Area (Km^2)**	**Area (hector)**	***Conversion Factor (Tones DM/ha)**	**DM Production (tones)**
Wetland	263.62	26361.87	1.9	50087.56
Forest	140.69	14068.67	1.2	16882.4
Bare land	781.39	78139.32	0.5	39069.66
Settlement	219.70	21970.38	0	0
Cropland	2233.25	223324.5	1.8	401984.1
Grassland	461.39	46139.13	2.9	133803.5
Shrubland	411.69	41169.1	1.9	78221.3
Total				720,048.5

***Source**: Amsalu & Addisu, (2014); Food and Agriculture Organization of the United Nations (FAO), (2018)

Table 2 presents the LULC data-based biomass production in the study area. Total dry matter production was 720,048.5 tons. The total dry matter production of Tena, Sherka, Lemu Belbelu, and Degalu Tejo districts was 171807, 188573, 148966, and 144305 tones, respectively (Appendix Table 2, Appendix Table 3, Appendix Table 4, and Appendix Table 5). The result shows the mean carrying capacity of grazing land in the study area was 0.32 TLU/ha/year (3.37 ha/TLU/Year) (Table 1).

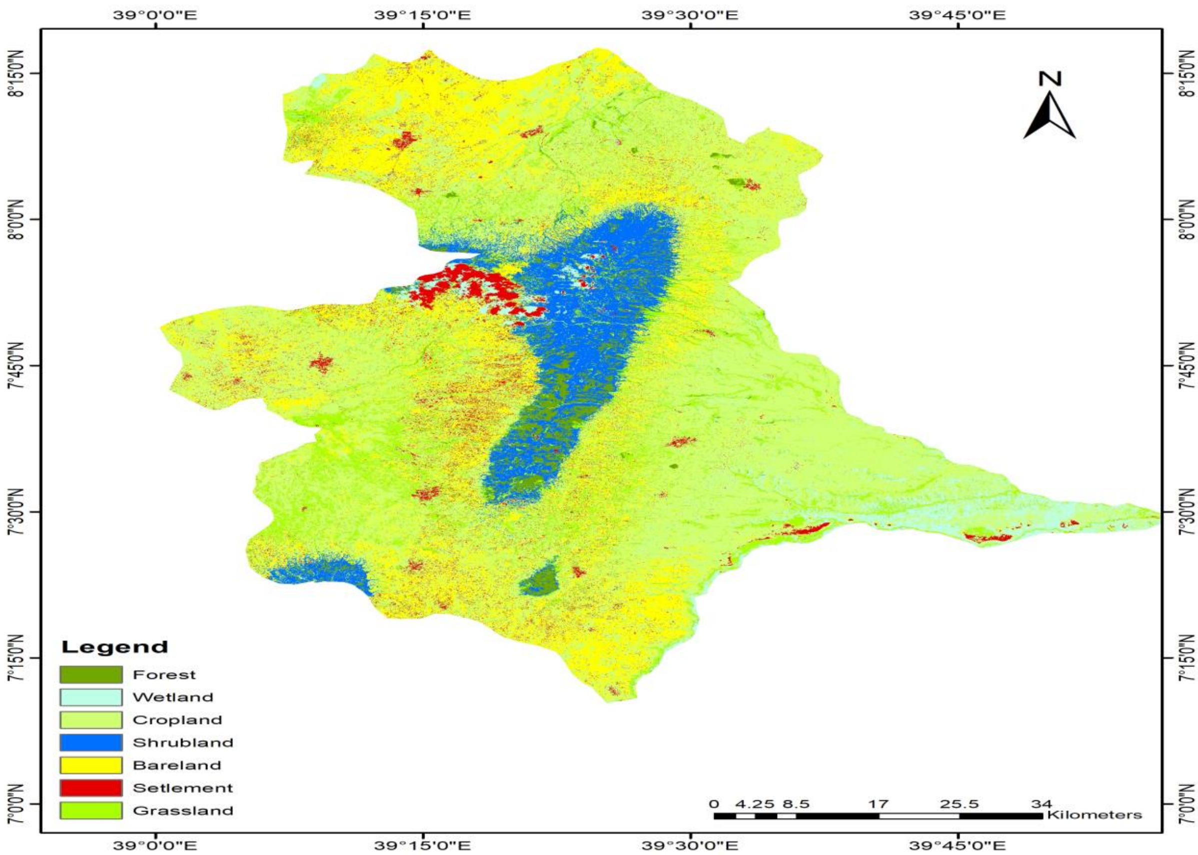


Figure 2: LULC map of the study area as derived from LANDSAT_8 (2022)

The mean carrying capacity of Tena, Sherka, Lemu Belbelu, and Degalu Tejo districts, and Galama mountain were 0.28 TLU/ha/year (2.64 ha/TLU/Year), 0.38 TLU/ha/year (2.66 ha/TLU/Year), 0.17 TLU/ha/year (5.94 ha/TLU/Year), 0.28 TLU/ha/year (3.56 ha/TLU/Year), and 0.49 TLU/ha/year (2.04 ha/TLU/Year), respectively (Table 2). These estimates are close to Winrok's (1992) permissible density for the highland zone of Africa. Recognizing the fact that the park is a protected habitat, which is being managed not for grazing land use but for conservation and several other ecosystem services other than grazing, the entire carrying capacity of grazing land in the park (Galama Mountain) did not consider as grazing land. Rather, half of the carrying capacity should be used for analysis and left the other for other ecosystem services. Hence, the sustainable carrying capacity of the protected area was 0.25 TLU/ha/year (1.02 ha/TLU/Year).

Table 4: Carrying capacity of the study area

Study Area	**Carrying Capacity (ha/TLU/ Year)**	**Carrying Capacity (TLU/ha /Year)**
Tena district	2.64	0.28
Sherka district	2.66	0.38

Lemu Belbelo district	5.94	0.17
Degalu Tejo district	3.56	0.28
Galama Mountain	2.04	0.49
Mean	3.368	0.32

3.2 Stocking Rates of Livestock

Table 5 presents livestock populations, available grazing lands, and stocking rates in the study area. The mean livestock stocking rate of Tena, Sherka, Lemu Belbelo, and Degalu Tejo districts were 0.04, 0.15, 0.15, 1.12, and 0.37 TLU/ha, respectively (Table 5). Winrok (1992) assessed consumable feed by zone at 0.19, 0.51, 0.72, and 0.76 tonnes of dry matter per hectare for the arid, semiarid, subhumid, and highland zones of Africa, respectively, which convert to permissible densities of 8 $TLUKm^{-2}$ (0.08 $TLUha^{-1}$), 22 $TLUKm^{-2}$ (0.22 $TLUha^{-1}$), 31 $TLUKm^{-2}$ (0.31 $TLUha^{-1}$) and 33 $TLUKm^{-2}$ (0.33 $TLUha^{-1}$). For highland areas, a maximum stocking rate of only 0.33 TLU ha^{-1} is recommended. Therefore, the stocking rate is far greater than the recommended level. Overstocking is thus a very serious problem in the park. Overgrazing is resulting in a deterioration of the quality of the grazing lands with an increase of unpalatable grasses. This has negative consequences for vegetation cover and composition and soil preservation.

Livestock is in direct competition with Mountain Nyala for grazing areas, confining the nyala to the steeper and less accessible areas, and is also impacting small mammal populations, which are the major food source for the Ethiopian wolf. Contact between wildlife and livestock is also increasing the risk of transmission of diseases. Therefore, if this grassland area should in the future again serve as a habitat for herbivores such as nyala and carnivores depending on grass rats, such as the Ethiopian Wolf, far-reaching measures that aim at excluding domestic animals from considerable areas of the grassland must be considered.

Table 5: Livestock populations, available grazing lands, and stocking rate in the study area.

Study Area	Total livestock (TLU)	Grazing Land (ha)	Stocking Rate (TLU/ha)
Tena district	96358.4	2406846.40	0.04
Sherka district	234822.4	1573445.00	0.15
Lemu Belbelo district	356688.4	2405746.80	0.15
Degalu Tejo district	247657.6	1752192.00	1.12
Galama Mountain		2406846.40	0.37
Mean			**0.37**

The results of this study showed that the total livestock population, annual feed demand, and annual feed supply in the study area were 935,526.8 TLU, 2,134,171 tones, and 653,651 tones, respectively (Table 6). The feed deficit was about 1,480,520 tonnes, and this can be achieved through grazing in the park. The highest pressure on the park is from Lemu Belbelo, followed by Degalu Tejo, Sherka, and Tena districts. Overall, annual feed availability is estimated at 653,651 tons against the requirement of 2,134,171 tons, resulting in a deficit of 69.4% annually. Therefore, the available feed is less than half of the feed required for maintenance. Feed deficit is thus a very serious problem for the communities in the study area.

Table 6: Livestock demand, supply, and balance in the study area

Study area	Total livestock (TLU)	Feed demand	Feed supply	Feed balance
Tena	96,358.4	219817.6	171807	-48010.6
Sherka	234,822	535688.6	188573	-347116
Lemu Belbelo	356,688	813695.4	148966	-664729
Degalu Tejo	247,658	564968.9	144305	-420664
Total	935,526.8	2134171	653651	-1480520

3.3 Socio-economic factors

3.3.1 Socio-economic and Demographic Characteristics of the Household

Of the total sampled population, 93.4% (n = 372) were males (Table 5). Most of the household (HH) heads were in their middle-aged group (M = 55.5, SD = 20.8). Around half of the household heads (46%, n = 178) had attained primary education as their highest education level, while only ten (6.8%) indicated secondary. However, 49.3% (n = 196) indicated that they have not attained any formal education (Table 5). About 38.7% (n = 154) of the HH heads derived their source of income from livestock and livestock products, 40.2% (n=160) of the HH heads derived from crop and livestock production, 15.1% (n=60) of the household heads derived from crop production while only 6.04% (n = 24) were derived from others (Table 5). The average HH size consisted of 7.5 (SD = 3.1) persons with a mean livestock number of 15.4 (SD= 8.02) TLU. Table 5 provides a summary of household profiles.

Table 7: Summary of households' socioeconomic and demographic characteristics

Variable	Items	N	M (SD)	Frequency	Percentage
Gender	Male			372	93.4%
	Female			26	6.6%
Age (years)			55.5 (20.8)		
Education level	Illiterate			109	27.4%
	Primary education			175	44%
	Secondary education			27	6.8%
	Read and write			87	21.9%
Household size		398	7.5 (3.1)		
Source of income	Livestock & livestock products			154	38.7%

	Crop and livestock production			160	40.2%
	Crop production			60	15.1%
	Others			24	6.04%
Livestock size			15.4 (8.02)		

N total sample size, M mean, SD standard deviation, n subset of the sample

3.3.2 Grazing livestock in the park

About 86.3% (n = 343) of the households reported that they have grazed their livestock in the park within the past 5 years (2016–2021). Following this, the perceived level of household livestock grazing in the park was assessed. The respondents were presented with statements in which they were asked to agree or disagree and indicate the level of their agreement or disagreement, ranging from very low dependency on the park for grazing their livestock (coded 1) to very dependency on the park to feed their livestock (coded 5). Concerning the itemized statements, results indicate that more than half of the households 77.87% (n= 310) were highly dependent on the park for their livestock feed, whereas about 17.1% (n= 68) and 5.03% (n= 20) were moderately and least dependent respectively.

3.3.3 Socio-economic factors influence grazing livestock in the Park

The binary logistic regression model was run to assess the predictive ability of the selected socio-economic factors on grazing livestock in the park. Preliminary analyses were conducted to test for multicollinearity, and no violations were observed. This finding indicates that a significant relationship exists between the explanatory variables and grazing livestock in the park (outcome variable). As presented in Table 3, only three predictors: age, livestock number, and education made a statistically significant contribution toward predicting grazing livestock in the park. Since the coefficient of age was negative, the odds of reporting grazing livestock in the park decreased with age (OR = 0.93). This suggests that an increase in the age of household heads results in a decrease a dependency on parks for livestock feed by a factor of 0.93, all other factors being equal. The finding implies that the youthful households were likely to graze livestock in the park compared to the middle-aged and the elderly.

Table 8: Logistic regression model for factors influencing livestock grazing in the park

Predictor	**B**	**SE**	**Exp(B)**	**95% CI for Exp(B)**	
				Lower	**Upper**
Gender	4.76	6.29	116.7	0.05	0.1
Age	-0.07	0.07	0.93*	53	57.5
Household size	-0.88	0.59	0.41	10.97	11.97
Education (Illiterate)	1.56	4.7	4.76*	0.23	0.32

Education (Read and write)	1.32	3.3	3.74*	0.39	0.49
Education (Primary)	-0.16	4.89	0.85*	0.18	0.26
Education (Secondary)	-4.05	13.79	0.02	0.05	0.1
Source of income (Livestock & livestock products)	0.02	14.13	1.02	0.34	0.44
Source of income (Crop & livestock production)	1.01	6.35	2.75	0.35	0.45
Source of income (Crop production)	-0.85	4.04	0.43	0.12	0.19
Source of income (other)	-1.31	4.20	0.27	0.04	0.1
Livestock number (TLU)	-1.13	0.52	0.32*	14.6	16.2
Constant	3.28	10.5	26.6		

B beta coefficients, SE stand error, Exp(B) odd ratio (OR) *P <0 .05

The coefficient of livestock number was positive, the odds of reporting grazing livestock in the park increased with livestock number (OR = 0.32). This suggests that an increase in the livestock number of household heads results in an increased dependency on the park for livestock feed by a factor of 0.32, all other factors being equal. The finding implies that the household with a large number of livestock were likely to graze livestock in the park compared to the households with a small number of livestock. Similarly, the coefficients of education were negative and the odds of reporting high park dependency decreased with the transition from primary (OR = 0.85) to secondary (OR = 0.02) education levels respectively. The result suggests that household heads with higher educational levels were more likely to depend on the park for their livestock feed compared to those with lower levels. On the other hand, the variables gender, household size, and source of income were not statistically significant but showed both positive and negative associations with grazing livestock in the park (Table 2).

4. Conservation Implications

The existing livestock stocking rate is higher than the carrying capacity of grazing lands in the Galama Mountain of Arsi mountain national park and the four districts surrounding Galama Mountain. The study signals the risk of severe overgrazing both inside the park considering the herbivores' wildlife and other wildlife in the areas. Both grazing lands inside the park and surrounding grazing lands are under severe pressure from livestock grazing and are overstocked more than the permissible capacity of the grazing lands. Annual feed availability is estimated at 653,651 tons against the requirement of 2,134,171 tons, resulting in a deficit of 69.4% annually. Socioeconomic factors such as age, livestock number, and education level significantly influenced household livestock grazing in the park. Overall, the livestock stocking rate is by far greater than the sustainable carrying capacity and available feed is less than half of the recommended annual feed demand. Overstocking and feed deficit in the surrounding districts are thus very serious problems for the park.

Livestock overgrazing is a threat to the biodiversity and ecosystem service of the park. Increased numbers of livestock are linked to a variety of threats to wildlife, especially the mountain nyala and Ethiopian wolf. Nyalas and other antelopes compete directly with livestock for food and are usually absent from areas where livestock numbers are high. Increased numbers of livestock are also detrimental to rodent populations, possibly reducing the prey base of the Ethiopian wolves. Contact between wildlife and livestock is also increasing the risk of transmission of diseases. Fire is mainly initiated by the local people for getting fresh forage for their livestock and eliminating large carnivores that potentially can attack livestock. Uncontrolled fire is devastating for the mountain Nyala which took refuge in small isolated patches of forest/Erica habitats. Fires imitated for this purpose destroy the critical remaining resource of mountain nyala in the dry season when resources are critically low and can kill mountain nyala itself. Hence, in collaboration with the local officials, the concerned community members, and civil society, the concessionaires and park management should work best to mitigate the threat from livestock grazing. Appropriate grazing pressure reduction strategy and grazing land improvement action are required to protect the biodiversity and ecosystem services that the park provides. The key factors bringing about a variation in park dependency for their livestock feed can be considered and factored into planning, designing, and implementing programs and activities for park sustainability.

5. References

Amsalu, T., & Addisu, S. (2014). Assessment of Grazing Land and Livestock Feed Balance in Gummara-Rib Watershed, Ethiopia. *Current Agriculture Research Journal*, *2*(2), 114–122. https://doi.org/10.12944/carj.2.2.08

Asefa, A., Mengesha, G., Shimelis, A., & Mamo, Y. (2016). Livestock Grazing in Afromontane Grasslands in the Northern Bale Mountains, Ethiopia: Implications for Bird Conservation. *Science, Technology and Arts Research Journal*, *4*(2), 112. https://doi.org/10.4314/star.v4i2.14

Ayalew, D., Sintayehu, T., Ermias, K., & Girma, M. (2019). Diversity and relative abundance of birds in Loka Abaya National Park, Sidama Zone, Southern Ethiopia. *International Journal of Biodiversity and Conservation*, *11*(8), 230–240. https://doi.org/10.5897/ijbc2019.1306

Bale Mountain National Park (BMNP). (2017). *Bale Mountains National Park: General Management Plan 2017-2027.*

Bantihun, G., Tadele, S., & Ameha, A. (2020). Avian Diversity in Dilifekar Block, Arsi Mountains National Park, Ethiopia. *Advances in Bioscience and Bioengineering*, *8*(1), 6. https://doi.org/10.11648/j.abb.20200801.12

Bauer, H., DIckman, A., Chapron, G., Oriol-Cotterill, A., Nicholson, S. K., Sillero-Zubiri, C., Hunter, L., Lindsey, P., & MacDonald, D. W. (2022). Threat analysis for more effective lion conservation. *Oryx*, *56*(1), 108–115. https://doi.org/10.1017/S0030605320000253

Belay, T., Melese, T., & Senamaw, A. (2022). Impacts of land use and land cover change on ecosystem service values in the Afroalpine area of Guna Mountain, Northwest Ethiopia. *Heliyon*, *8*(12), e12246. https://doi.org/10.1016/j.heliyon.2022.e12246

Bernard, E., Penna, L. A. O., & Araújo, E. (2014). Downgrading, downsizing, degazettement, and reclassification of protected areas in Brazil. *Conservation Biology*, *28*(4), 939–950. https://doi.org/10.1111/cobi.12298

Biru, Y., Tessema, Z. K., & Urge, M. (2017). Perception and attitude of pastoralists on livestock-wildlife interactions around Awash National Park, Ethiopia: implication for biodiversity conservation. *Ecological Processes*, *6*(1). https://doi.org/10.1186/s13717-017-0081-9

Diriba, G., Tamene, S., Mengesha, G., & Asefa, A. (2020). Diversity of medium and large mammals in the Loka Abaya National Park, southern Ethiopia. *Ecology and Evolution*, *10*(18), 9896–9905. https://doi.org/10.1002/ece3.6649

Ethiopian Wildlife Conservation Authority. (2017). *National Action Plan for the conservation* *of the Ethiopian wolf. Revised version 2017*.

Fenetahun, Y., Yuan, Y., Xu, X. W., & Wang, Y. D. (2022). Borana rangeland of southern Ethiopia: Estimating biomass production and carrying capacity using field and remote sensing data. *Plant Diversity*, *44*(6), 598–606. https://doi.org/10.1016/j.pld.2022.03.003

Food and Agriculture Organization of the United Nations (FAO). (2018). *Report on feed inventory and feed balance 2018 in Ethiopia*.

Garekae, H., Thakadu, O. T., & Lepetu, J. (2017). Socio-economic factors influencing household forest dependency in Chobe enclave, Botswana. *Ecological Processes*, *6*(1). https://doi.org/10.1186/s13717-017-0107-3

Gebeyehu, A. K., Sonneveld, B. G. J. S., & Snelder, D. (2021). Identifying hotspots of overgrazing in pastoral areas: Livestock mobility and fodder supply–demand balances in Nyangatom, Lower Omo Valley, Ethiopia. *Sustainability (Switzerland)*, *13*(6). https://doi.org/10.3390/su13063260

Giday, K., Humnessa, B., Muys, B., Taheri, F., & Azadi, H. (2018). Effects of livestock grazing on key vegetation attributes of a remnant forest reserve: The case of Desa'a Forest in northern Ethiopia. *Global Ecology and Conservation*, *14*, e00395. https://doi.org/10.1016/j.gecco.2018.e00395

Girma, Z., Chuyong, G., Evangelista, P., & Mamo, Y. (2018). Vascular plant species composition, relative abundance, distribution, and threats in Arsi Mountains National Park, Ethiopia. *Mountain Research and Development*, *38*(2), 143–152. https://doi.org/10.1659/MRD-JOURNAL-D-17-00006.1

Girma, Z., Chuyong, G., & Mamo, Y. (2018). Impact of Livestock Encroachments and Tree Removal on Populations of Mountain Nyala and Menelik's Bushbuck in Arsi Mountains National Park, Ethiopia. *International Journal of Ecology*, *2018*. https://doi.org/10.1155/2018/5193460

Habte, M., Eshetu, M., Legesse, A., Maryo, M., & Andualem, D. (2021). Land use/cover change analysis and its implication on livestock feed resource availabilities in southeastern rangeland of Ethiopia. *Livestock Research for Rural Development*, *33*(3), 1–23.

Israel G.D. (1992). *Determining sample size.*

Jacob, M., Frankl, A., Hurni, H., Lanckriet, S., De Ridder, M., Guyassa, E., Beeckman, H., & Nyssen, J. (2017). Land cover dynamics in the Simien Mountains (Ethiopia), half a century after establishment of the National Park. *Regional Environmental Change*, *17*(3), 777–787. https://doi.org/10.1007/s10113-016-1070-8

Kidane, Y., Stahlmann, R., & Beierkuhnlein, C. (2012). Vegetation dynamics, and land use and land cover change in the Bale Mountains, Ethiopia. *Environmental Monitoring and Assessment*, *184*(12), 7473–7489. https://doi.org/10.1007/s10661-011-2514-8

Kostin, D. S., Kasso, M., Komarova, V. A., Martynov, A. A., Gromov, A. R., Alexandrov, D. Y., Bekele, A., Zewdie, C., Bryja, J., & Lavrenchenko, L. A. (2019). Taxonomic and genetic diversity of rodents from the Arsi Mountains (Ethiopia). *Mammalia*, *83*(3), 237–247. https://doi.org/10.1515/mammalia-2017-0135

Marino, J., & Sillero-Zubiri, C. (2011). Canis simensis. *The IUCN Red List of Threatened Species, 10*(2011–1), 2011-1.

Mekbeb, E. T., Kumara, W., & Addisu, A. (2019). Threats and their relative severity and driving forces in the African Elephant range wildlife protected areas of Ethiopia. *International Journal of Biodiversity and Conservation*, *11*(7), 187–198. https://doi.org/10.5897/ijbc2019.1298

Meshesha, D. T., Moahmmed, M., & Yosuf, D. (2019). Estimating carrying capacity and stocking rates of rangelands in Harshin District, Eastern Somali Region, Ethiopia. *Ecology and Evolution*, *9*(23), 13309–13319. https://doi.org/10.1002/ece3.5786

Muluneh, M. G. (2021). Impact of climate change on biodiversity and food security: a global perspective—a review article. *Agriculture and Food Security*, *10*(1), 1–25. https://doi.org/10.1186/s40066-021-00318-5

Nashipay, M. L., Mabwoga, S., & Konana, C. (2022). An Assessment of the Ecosystem-Based Adaptation Approach for Flood Risk Management in the Upper Suswa-Magadi Catchment. *African Journal of Climate Change and Resource Sustainability*, *1*(1), 26–36. https://doi.org/10.37284/ajccrs.1.1.952

Piipponen, J., Jalava, M., de Leeuw, J., Rizayeva, A., Godde, C., Cramer, G., Herrero, M., & Kummu, M. (2022). Global trends in grassland carrying capacity and relative stocking density of livestock. *Global Change Biology*, *28*(12), 3902–3919. https://doi.org/10.1111/gcb.16174

Rabira, G., Tsegaye, G., & Tadesse, H. (2015). The diversity, abundance and habitat association of medium and large-sized mammals of Dati Wolel National Park, Western Ethiopia. *International Journal of Biodiversity and Conservation*, *7*(2), 112–118. https://doi.org/10.5897/ijbc2014.0808

Serunkuma, D., Olso, B. (1998). *Land Management in Uganda: Characterization of Problems and Hypotheses about Causes and Strategies for Improvement; Project on Policies for*

Improved Land Management in Uganda.

Tesema, M. (2022). *Ethiopia-National-Biodiversity-Threat-Assessment_Final-Report_Mekbeb-and-Addisu_10_02_2022*. *February*.

UNEP-WCMC. (2022). *Protected Area Profile for Arsi Mountains from the World Database of Protected Areas.*

Vial, F. (2010). *Conservation science for common ground: developing the necessary tools to manage livestock grazing pressure in Bale Mountains National Park, Ethiopia*. *2010*. http://theses.gla.ac.uk/2012/

Winrok. (1992). Assessment of animal agriculture in sub-Saharan Africa. *Assessment of Animal Agriculture in Sub-Saharan Africa.*, xxi + 125-xxi + 125. http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=19931859210&site=ehost-live

Worku, E. A., Atickem, A., Bro-Jørgensen, J., Bekele, A., Evangelista, P., & Stenseth, N. C. (2021). Human activities increase vigilance, movement and home range size of the endangered mountain nyala (Tragelaphus buxtoni) at the cost of foraging and resting. *Global Ecology and Conservation*, *32*(November). https://doi.org/10.1016/j.gecco.2021.e01900

Yamane T. (1967). *Statistics: An introductory analysis.*

6. Appendices

Appendix Table 1: Operational definition of landscape classes in the study Areas

Class	Operational definition
Forest	Areas that are covered with trees with closed canopies. It was made to include human made plantation forest, riverine forests, dry ever green forest and moist mountain forest and woodlands.
Shrubland	Includes shrub, bush with grass under growth and in some cases scattered wood trees are present.
Grassland	Both communal and or private grazing lands that are used for livestock grazing. The land is covered by small grasses, grass like plants and herbaceous species. It also includes land covered with mixture of small grasses, grass like plants and shrubs less than 2 m and it is used for grazing.
Agriculture	Made to include areas allotted to rain fed cereal crops (e.g., Corn, Barley, Teff, and Wheat), cash crops and horticultural crops particularly vegetables (e.g., onion, potato, and cabbage).
Settlement	Urban areas and clustered large rural settlement.
Bareland	Comprises exposed rocks, bare ground due to land clearing, burning, fallowing, or excessive erosion, and sedimentations
Wetland	The afroalpine lakes, the rivers, and the hydroelectric dam

Appendix Table 2: Land-use land cover data based on dry matter (DM) production estimation (Tena)

LULC Types (2022)	**Area (%)**	**Area (hactar)**	***Conversion Factor (tonnes DM/ha)**	**DM Production (tonnes)**
Wetland	1.76	1399.42	1.9	2659
Forest	4.12	4177.68	1.2	5013
Bare land	12.63	12806.82	0.5	6403
Settlement	2.12	2149.68	0	0
Cropland	49.10	49787.40	1.8	89617
Grassland	9.68	9815.52	2.9	28465
Shrubland	20.58	20868.12	1.9	39649
Total	100.00	**79512.6**		171807

***Source**: Amsalu and Addisu (2014); FAO (2018).

Appendix Table 3: Land-use land cover data based on dry matter (DM) production estimation (Sherka)

LULC Types (2022)	**Area (%)**	**Area (hactar)**	***Conversion Factor (tonnes DM/ha)**	**DM Production (tonnes)**
Wetland	16.46	18904.31	1.9	35918
Forest	3.6	3650.40	1.2	4380
Bare land	3.58	3630.12	0.5	1815
Settlement	2.55	2585.70	0	0
Cropland	60.11	60951.54	1.8	109713
Grassland	9.62	9754.68	2.9	28289
Shrubland	4.39	4451.46	1.9	8458
Total	100.00	**114850**		188573

***Source**: Amsalu and Addisu (2014); FAO (2018).

Appendix Table 4: Land-use land cover data based on dry matter (DM) production estimation (Lemu Belbelo)

LULC Types (2022)	**Area (%)**	**Area (hectare)**	***Conversion Factor (tonnes DM/ha)**	**DM Production (tonnes)**
Wetland	1.98	3077.12	1.9	5847
Forest	1.42	1439.88	1.2	1728
Bare land	29.86	30278.04	0.5	15139
Settlement	3.29	3336.06	0	0
Cropland	47.97	48641.58	1.8	87555
Grassland	8.77	8892.78	2.9	25789
Shrubland	6.7	6793.80	1.9	12908
Total	100.00	155410		148966

***Source**: Amsalu and Addisu (2014); FAO (2018).

Appendix Table 5: Land-use land cover data based on dry matter (DM) production estimation (Degalu Tejo)

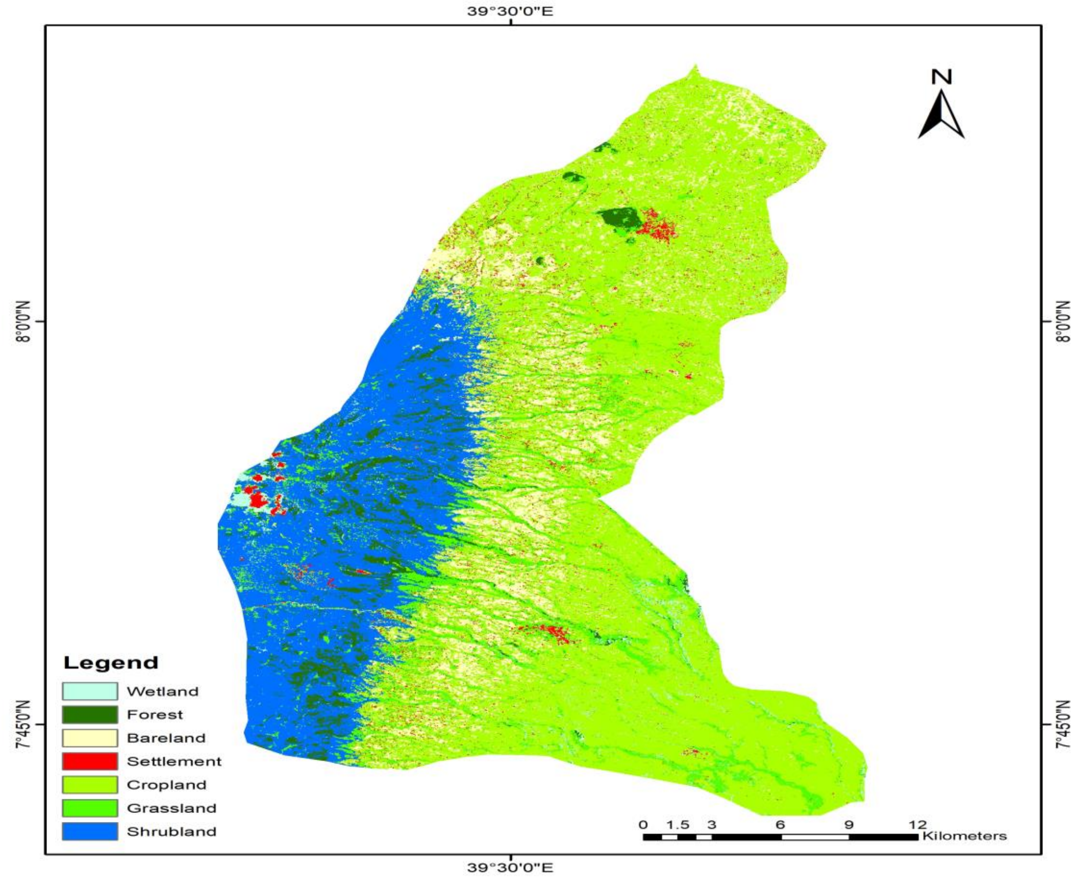
LULC Types (2022)	**Area (%)**	**Area (hectare)**	***Conversion Factor (tonnes DM/ha)**	**DM Production (tonnes)**
Wetland	3.5	3549.00	1.9	6743
Forest	3.61	3660.54	1.2	4393
Bare land	19	19266.00	0.5	9633
Settlement	11.16	11316.24	0	0
Cropland	45.45	46086.30	1.8	82955
Grassland	7.17	7270.38	2.9	21084
Shrubland	10.12	10261.68	1.9	19497
Total	100.00	**101400**		144305

***Source**: Amsalu and Addisu (2014); FAO (2018).

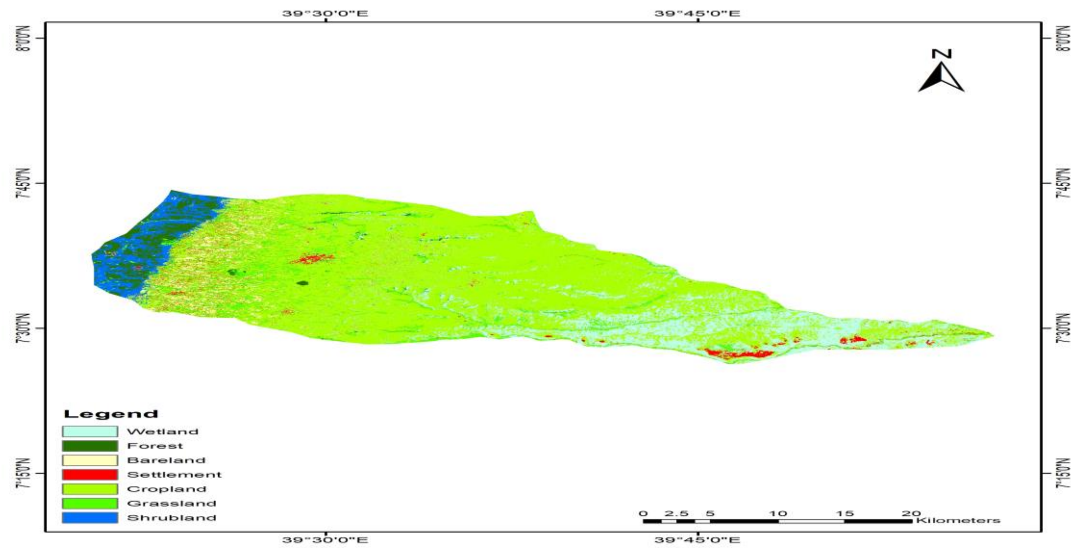
Appendix Table 6: Land-use land cover data based on dry matter (DM) production estimation (Galama Mountain)

LULC Types (2022)	**Area (%)**	**Area (km^2)**	***Conversion Factor (Tones DM/ha)**	**DM Production (Tones)**
Wetland	2.95	1545.80	1.9	2937
Forest	3.63	3680.82	1.2	4417
Bare land	20.73	21020.22	0.5	10510
Settlement	6.23	6317.22	0	0
Cropland	39.5	40053.00	1.8	72095
Grassland	20.62	20908.68	2.9	60635
Shrubland	6.34	6428.76	1.9	12215
Total	**100.00**	**52400**		162809

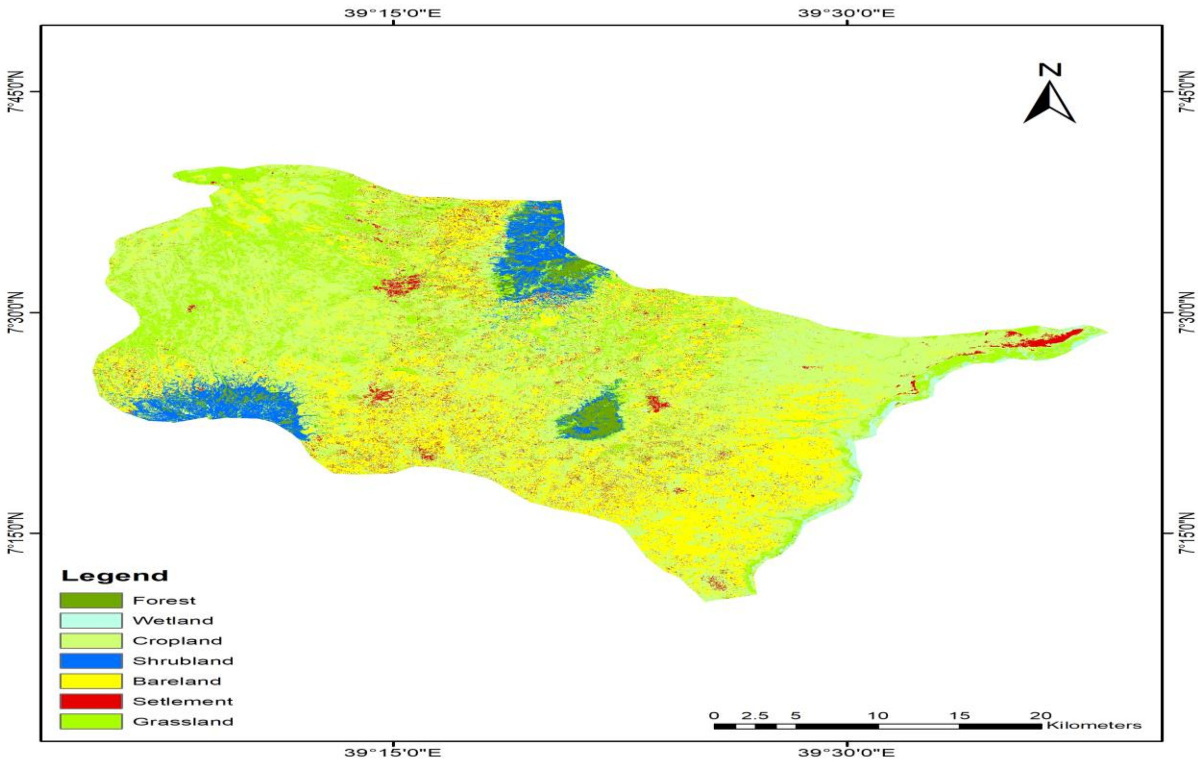
***Source**: Amsalu and Addisu (2014); FAO (2018).



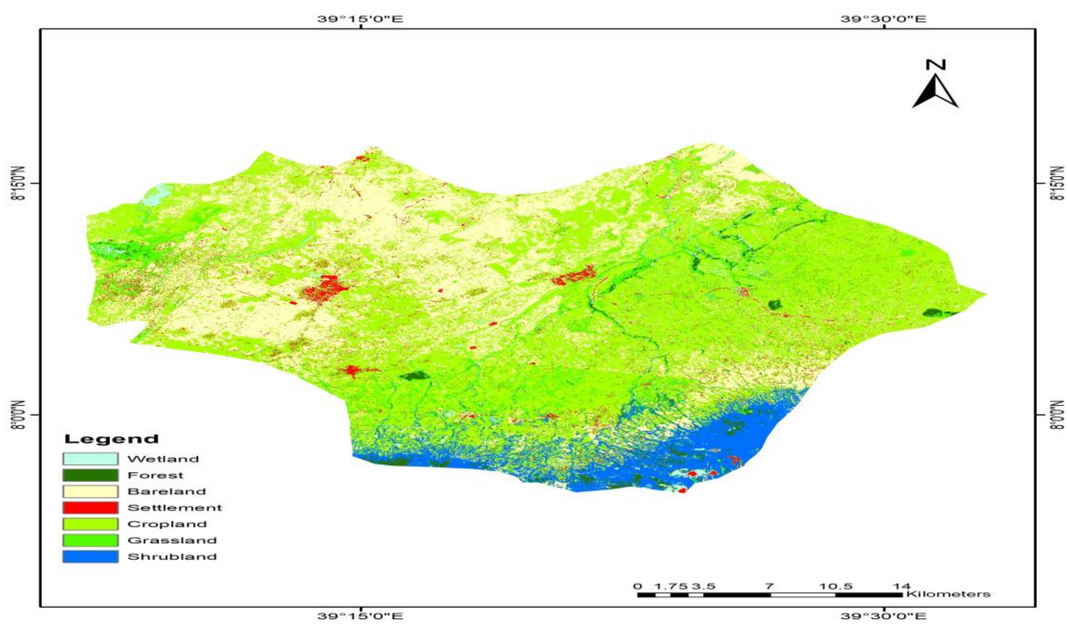
Appendix Figure 1**:** Land use and cover map of the study area (Tena district) as derived from LANDSAT_8 (2022)



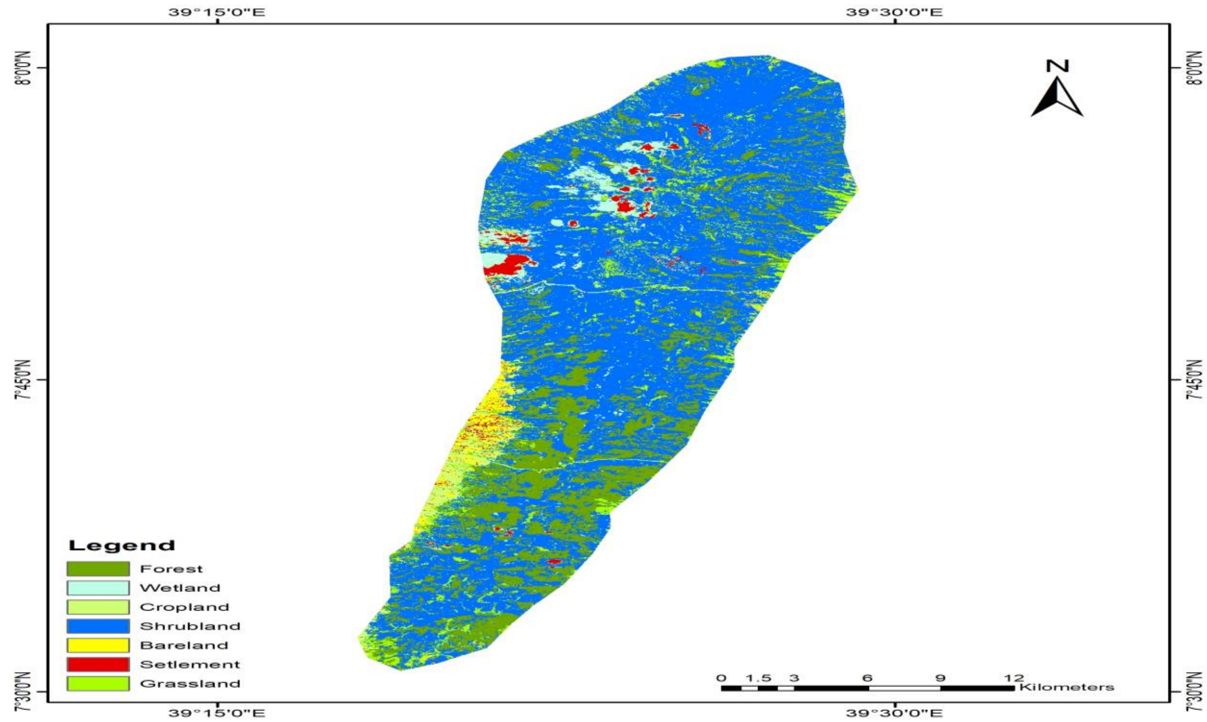
Appendix Figure 2**:** Land use and cover map of the study area (Sherka) as derived from LANDSAT_8 (2022)



Appendix Figure 3**:** Land use and cover map of the study area (Lemu Belbelo) as derived from LANDSAT_8 (2022)



Appendix Figure 4**:** Land use and cover map of the study area (Degalu Tejo district) as derived from LANDSAT_8 (2022)



Appendix Figure 5**:** Land use and cover map of the study area (Galama Mountain) as derived from LANDSAT_8 (2022)