




An Analysis of Occurrences, Impacts on Livestock and Existing Management Strategies of Invasive *Ipomoea hildebrandtii* Vatke in Southern Rangelands of Kenya

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Abstract

Background: *Ipomoea hildebrandtii* Vatke, an invasive weed is a key limitation to livestock production in pastoral and agro-pastoral Southeastern rangelands of Kenya. The weed is reported to reduce forage availability, disrupt normal grazing patterns, and livestock poisoning. Overgrazing, recurring droughts, and land-use changes has greatly contributed to its spread. **Methods:** Weed information data was collected through field questionnaires, direct observations, key informant interviews and focus group discussions. Remote sensing using satellite imagery was utilized to visualize and analyze weed distribution. **Results:** The weed is prevalent in degraded grazing areas, along seasonal rivers, and mined fields. Weed infestation was statistically significant between the counties ($p < 0.001$) with Kajiado county recording the highest infestation. Weed uprooting and burning were reported as the management methods in use. Run-off water was identified one of the key mechanisms of spreading. Between 2019 and 2024, *Ipomoea hildebrandtii* coverage grew by 26%, in the study counties. **Conclusions:** *Ipomoea hildebrandtii* poses a significant challenge to livestock production in the region, necessitating the development of localized management strategies. Engaging and synthesizing the community on the impacts of this invasive weed, alongside disseminating information on available management options, is essential for sustaining community livelihoods.

Subject Areas

Environmental Sciences

Keywords

Invasive Species, *Ipomoea hildebrandtii*, Pasture, Rangelands Restoration, Invasive Weed Management

1. Introduction

Rangelands are the natural and pristine ecosystems in arid and semi-arid areas mainly occupied by diversity of vegetation including forbs, grass, grass-like plants and shrubs and are majorly suited for grazing [1]. Rangelands represent the largest global land resource, accounting for 25% of the total land mass [1]-[4]. Rangelands constitute to about 80% of total land mass in Australia [5] [6], 30% in the United States of America [7], and 40% of China's land mass [8].

In Africa, rangelands occupy approximately 66% of the total land mass [9], with an estimated 74% in Tanzania [10] [11], 65% in Ethiopia [12], 88% in Kenya [13] [14], and 44% in Uganda. They are important ecosystems providing both socio-economically and ecologically beneficial ecosystem services [3]. Rangeland ecosystems are critical in the provision of fodder for livestock, support livelihoods through provision of food, milk, meat and assorted livestock products generating income [1] [15]. For instance, in Africa, rangelands are essential for the livelihoods of pastoralist communities and for maintaining ecological balance [16]. The rangeland ecosystems are classified as global biodiversity hotspots as they host several wildlife species and provide essential ecosystem connectivity [17]. Apart from providing habitats for numerous wild fauna and flora [18], rangelands are vital for domestic livestock productivity. In Kenya, livestock contributes 45% of the agricultural GDP and is a major source of livelihood across the arid, semi-arid, and small-holder farming systems [19].

Ecologically, rangelands are significant in providing wildlife habitats and acting as watershed catchments for river systems. They are crucial ecosystems for the storage of organic Carbon (C) Worldwide, as it is estimated that rangelands sequester up to about 30% of the total global soil [20]. These are used for livestock production through a few commercial ranches and pastoralism [21]. These lands play a critical role in the exchange of GHG between the biosphere and atmosphere with fluxes being linked to its management practices [22].

In the recent past, rangelands are increasingly facing degradation due to: over-grazing, climate change, alien plant invasion (invasive species) proliferation, and unsustainable land management practices [23]. According to the Global Invasive Database [24], there are close to 210 invasive plant species in Eastern Africa. The distribution of these alien plant species in each country is as follows: Kenya (49),

Tanzania (48), Uganda (33), Somalia (11), and the rest are spread in the other Eastern African countries [25]. In southern rangelands counties of Kenya including Kajiado, Makueni and Taita Taveta counties, the invasion by shrubs has been cited as one of the major causes of rangeland deterioration [26]. One of the species, which is a problem invasive species in natural and established pastures in Kajiado County, is *Ipomoea hildebrandtii*. This invasive species has been associated with decreased grass cover and biomass, which in turn impacts livestock productivity and the economic stability of pastoral communities (see **Figure 1**).



Figure 1. Competitive exclusion of palatable forage by infestation of the invasive weed *I. hildebrandtii* in grazing land in Kajiado province, Kenya: **left**, refusal of unpalatable weed by cattle; **right**, a livestock owner standing in a weed thicket showing smothering effect on other plant species.

The species is considered among the least preferred forage options for grazing livestock [27]. *I. hildebrandtii* is a fast spreading, creeping annual herb commonly found in the semi-arid regions of southern Kenya, rapidly colonizing areas soon after the rainy season begins [28]. The spread of invasive species, particularly *I. hildebrandtii*, has significantly altered the ecological balance of most rangelands [29]. *I. hildebrandtii* competes aggressively with native grasses, reducing forage availability and quality, and altering soil properties [30]. The species is primarily found in disturbed or degraded areas. It possesses key traits typical of invasive plants, including rapid growth and expansion, widespread dispersal and reproduction, or the ability to produce fewer offspring with high efficiency [31]. The species is also highly competitive with native plants, effectively competing for nutrients, space, sunlight, and water. The focus of this study was to understand the extent of invasion of *I. hildebrandtii* in the southern rangelands of Kenya, particularly in Kajiado, Makueni and Taita Taveta Counties. It also explored the community perceptions, impacts and the control interventions for the *I. hildebrandtii*.

2. Materials and Methods

2.1. Description of Study Sites

The study sites were in Makueni, Taita Taveta and Kajiado Counties which amount

to 10% of the arid and semi-arid areas ASALs of southern Kenya (Figure 2). Makueni County falls between latitude 1°35' and 3°00' S and longitude 37°10' and 38°30' E with an area of 7965.8 km² Taita Taveta falls between latitude 2°30' and 4°10' S and longitudes 37°30' and 39°30' E with an area of 17,084 km² Kajiado County lies between latitude 1°0' and 3°0' S and longitude 36°5' and 37°5' E with an area of 21,901 km². These regions were specifically selected because of their active involvement in the Agricultural Research Supports Program Phase Two (ARSP-II), launched 1998 to promote the development and dissemination of fodder production technologies in the ASALs of Kenya [32]. The methods and technologies that were introduced and adopted by the communities in these areas include participatory rangeland regeneration, and range reseeding with indigenous species through over-sowing [33] [34]. These practices were adopted not only to provide feed for their livestock but also offer additional income through selling hay and grass seed mainly to local livestock keepers and complement the fodder value chain [35].

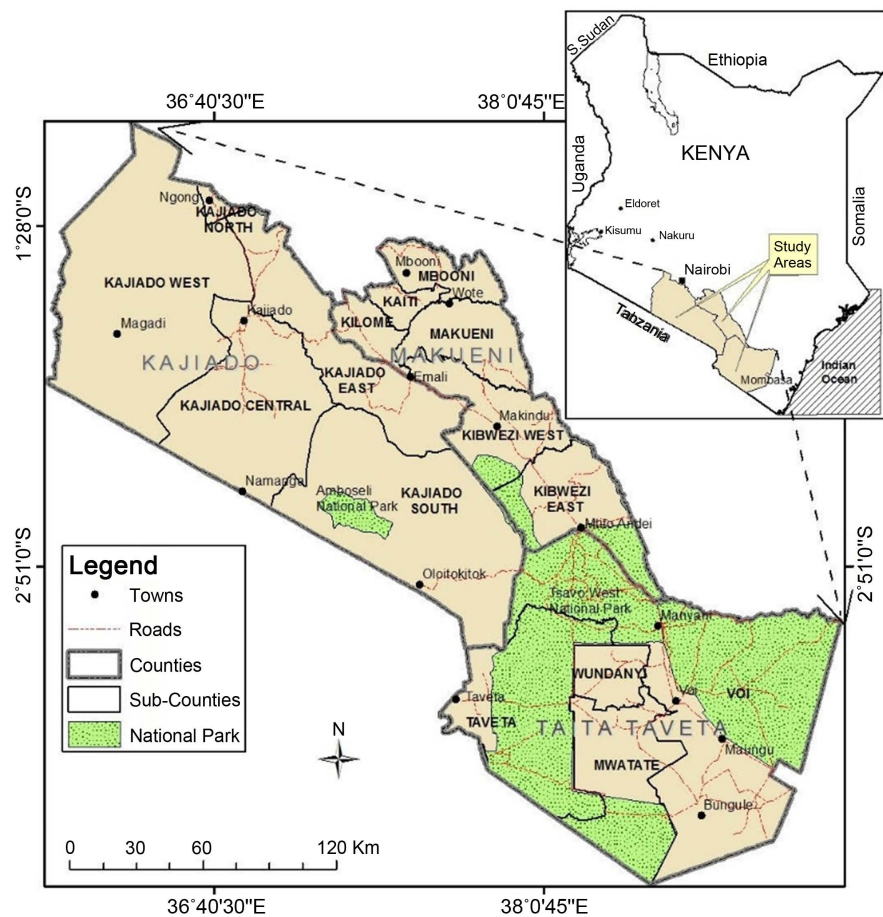


Figure 2. Map of Kenya showing the counties of Kajiado, Makueni and Taita Taveta Counties.

Fodder production in these areas is rainfall dependent, with preferred grass species including those that are drought resistant, that are palatable and adapted to the local environments. Some of these grass species include *Eragrostis superba* Es,

Cenchrus ciliaris (Cc), *Chloris roxburghiana* (Cr) and *Enteropogon macrostachyus* (Em) [34]. Additionally, these grass species are considered based on their ability to self-propagate and reducing the need for reseeding after first year of establishment. The primary sources of grass seed are the Kenya Agricultural and Livestock Research Organization (KALRO) while other were obtained from naturally growing fodder fields [35]. The production is small scale and dependent on farmers own resources and use of locally available cheap resources such as family labor and ox plough during land preparation and other production activities. The farmers mainly plant grass through seed broadcasting methods and control weeds by uprooting sprouting unwanted plant [33]-[35].

Taita Taveta is in the southeastern Kenya with diversity in ecological characteristics in topography from the lowlands of Taveta to the highlands of Taita hills. The main soil types are *Haplic Acrisols*, *Eutric Cambisols*, *Chromic Luvisols*, *Regosols*, *Humic Cambisols* and *Nitisols*. Taita Taveta county receive an annual rainfall of 400 to 1500 mm with a temperature range of 20°C and 28°C whereas Kajiado county has annual rainfall ranging from 450 to 1454 mm and temperature range between 22°C and 27°C and all influenced by season and topography.

Kajiado County is dominated by arid to semi-arid grasslands with open grass plains, acacia woodlands, rocky thorn bush lands, swamps and marshlands [36]. The soils are poorly drained and shallow clayey soils in the floodplains; brown calcareous clay loams, sandy soils, ash and pumice soils in the higher elevations; and basement rock soils which dominate large areas of the County, making pastoralism the ideal land use in most parts of the County [36]. In Makueni County the main vegetation cover varies from Commiphora, Accacia and related genera to shrubby habitat, dominated with various grass species such as *Cenchrus ciliaris*, *Eragrostis superba*, *Chloris roxburghiana* and *Enteropogon macrostachyus* [37]. The common soil types in the area are Ferrasols, Cambisols and Luvisols prone to erosion when heavy rains occur.

These study sites are characterized by erratic and unpredictable rainfall patterns as well as more extreme and extended drought [38] [39]. The rainfall seasons vary from long rains been from March to May and short rains from October to December [38] [39], with Makueni county experiencing an annual rainfall ranging from 300 to 1250 mm [40] [41], temperatures in the areas range between 12°C and 35°C [38] [41]. Small-scale farming and livestock keeping are the most common economic activities in these areas [39]. Land tenure and land use in Kajiado County is seemingly changing faster with land privatization replacing the communal group system; with land fragmentation and commercialization of communal lands to secure title deeds becoming common. Makueni County has high prolific value in horticulture and dairy farming, especially the hilly parts. The lowlands are used for livestock keeping, cotton and fruit production, and the main fruits grown. The main food crops produced in Makueni are maize, green grams, pigeon peas and sorghum [41]. Land tenure system in Taita Taveta is significantly changing also with formalization of land titles and recognition of communal land

right under county land management board, with heavy reliance on agropastoralism, ranching, mining and tourism being the key economic activities.

2.2. Data Collection and Analysis

2.2.1. Mapping the Occurrences of *I. hildebrandtii* Vatke in the Study Sites

The study focused on three counties (Kajiado, Taita Taveta and Makueni) where there is prevalence of *I. hildebrandtii* reducing livestock forage as well as adversely compromising the community livelihood options. Remote sensing was employed to map and analyze the spatial distribution of *I. hildebrandtii* across Kajiado, Makueni, and Taita Taveta counties in Kenya. Multispectral imagery from Sentinel-2, accessed and processed within the Google Earth Engine (GEE) platform, was used to derive biophysical indicators relevant to the detection of vegetation dynamics associated with invasive species.

A total of 62 vegetation indices (VIs) were selected from the Index Database, focusing on indices sensitive to plant stress, chlorophyll concentration, and moisture content. JavaScript equivalents of these indices were obtained from Sentinel Hub and validated against published literature. The VIs were computed separately for both dry and wet season Sentinel-2 imagery. For each season, median composites were generated by calculating the pixel-wise median across temporal image series, producing representative multiband images. These images included both original Sentinel-2 spectral bands and computed vegetation indices, amounting to 72 variables per season. Seasonal composites were subsequently stacked, resulting in a final image with 144 variables.

Environmental variables influencing *Ipomoea* distribution, including elevation, slope, aspect, hill shade, and seasonal rainfall, were also incorporated. Elevation data were sourced from the NASA Shuttle Radar Topography Mission (SRTM) at 30-meter resolution, and topographic derivatives were generated from this dataset. Seasonal rainfall data were retrieved from the CHIRPS dataset. The integration of these environmental factors expanded the composite dataset to 150 variables. Classification of *I. hildebrandtii* occurrence was conducted using two supervised nonparametric machine learning algorithms: Random Forest (RF) and Support Vector Machine (SVM). The RF algorithm, configured with 1000 trees and default parameters, was selected due to its robustness and superior classification performance. The SVM classifier, employing kernel-based transformations for non-linear separation, was also tested using default settings. Both classifiers were executed in the GEE environment.

Model performance was evaluated using a 70:30 split for training and testing data, with assessment based on Overall Accuracy (OA) and the Kappa coefficient. Additional accuracy verification was conducted through visual comparison with very high-resolution Google Earth imagery, enabling the identification of misclassified areas and enhancing the interpretability of the classification results. The final output—a classified map of *I. hildebrandtii* distribution—was generated at a spatial resolution of 20 meters.

2.2.2. Assessment of the Community Perceptions, and Effect of *I. hildebrandtii* on Herbage Plant Species

The study sites were selected with available information on occurrence and distribution of the weed. Systematic sampling method was used to select homesteads. Using the estimated total population in each county, a target sample size was determined. A purposive sampling will be used to identify the villages in each county based on the weed occurrence and villages within the locations with high infestation of the invasive weed. The selection villages were confirmed and supported by information provided by county livestock office, clergy and local administration. Selection of respondents for survey questionnaire in the study villages was selected on basis of probability sampling techniques [42] [43]. The sample size was determined using the Fisher's Equation [44] [45].

$$n = \frac{t^2 \times p(1-p)}{m^2}$$

where: n = required sample size;

t = confidence level at 95%;

p = proportion of target population with the desired characteristics.

Calculation:

$$n = \frac{1.96^2 \times 0.6(1-0.6)}{0.05^2} = 3.16$$

The sample size was increased by 5% to account for contingencies including recording errors, to give a total of 332 respondents per county. In each county a target of 350 respondents were targeted. In Kajiado County with 5 sub-counties, 70 respondents per sub-county were targeted. With 6 sub-counties in Makueni County 58 respondents were targeted in each of the sub-counties. In Taita Taveta County 88 respondents in each sub-county were targeted. A questionnaire was administered to a total of 1030 respondents with Kajiado 354, Makueni 366 and Taita Taveta 310 respondents.

In addition, ten Focus Group Discussions (FGDs) in each county comprising an average of 25 participants and six key informant interviews were conducted in each county to obtain more insights into the data collected during interviews. The FGD and key informant interviews included women, men, the youth, religious leaders and opinion leaders, members of national and county governments. The data collected was on the weed occurrence, distribution, topography and soil type that is preferred by the weed, dispersal mechanisms, predisposing factors for weed spread. In addition, data on effect of weed on animals if consumed, control method currently used by the communities to manage the weed as well as information gaps on management of the weed.

2.3. Statistical Methods

Survey data statistical analyses were performed in the R software environment (R

Core Team, 2018) to obtain means, frequencies, and percentages. Pearson's chi-squared test [46] and Kruskal-Wallis rank sum test were used to test the degree of association between the variables.

3. Results

3.1. Occurrences of *I. hildebrandtii* in Study Sites between 2019 and 2024

There was change in area of the various LULC between 2019 and 2024 (**Figure 3**, **Figure 4**). For 2019, dates 1/3/2019-20/4/2019 for dry season and 1/11/2019-31/01/2020 for wet season. In classification same month was not used between 2019 and 2024 due to different start and end of dry and wet seasons 2023/2024 classification because the wet and dry seasons were different (as per NDMA monthly reports).

The result show *Ipomoea hildebrandtii* grew by 26% from 6602 ha to 8316 ha (**Table 1**). Due to human activity such as deforestation, woody vegetation reduced by 32%, this area could be part of built area which increased by 16%, bare land by 43% and grassland by 46%. Farmland hectare reduced by 19%, from 5063 ha to 4111 ha which could be scaling down due drought but also prepared crop land being classified as bare ground. Increase of other herbaceous plants was associated with abandoned farmland being colonized by shrubs and herbaceous species. Some of the changes could be due to conversion of the land to urban development. The changes show reduction of natural ecosystem which is a main cause for increase invasive species.

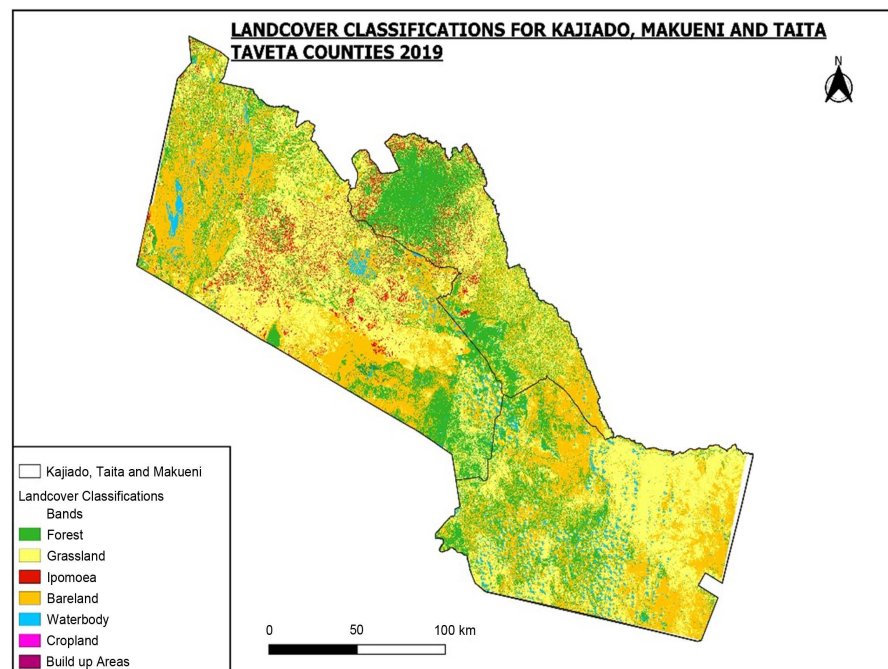


Figure 3. The distribution and occurrence of *I. hilderbrandtii* relative to other landcover classification in the 3 counties in 2019.

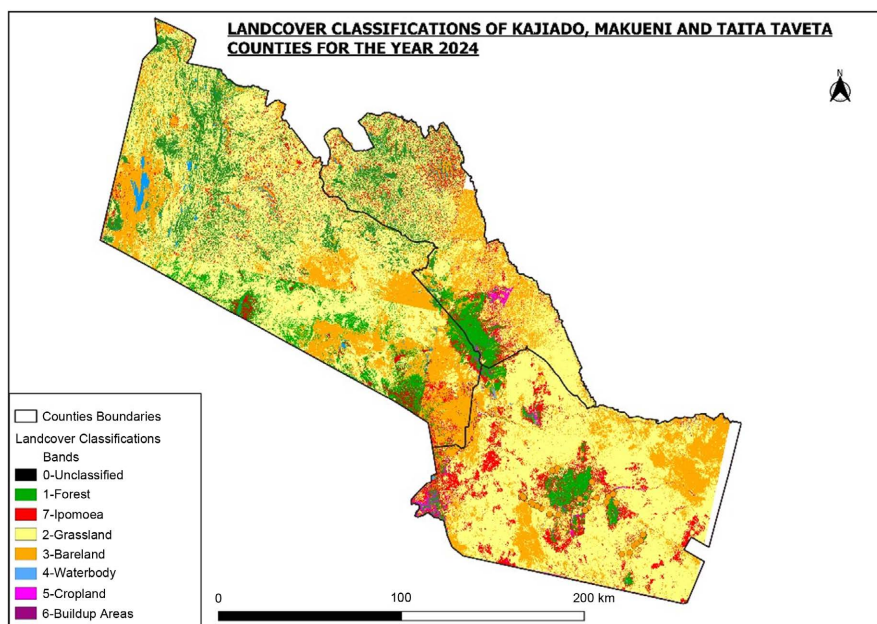


Figure 4. The distribution and occurrence of *I. hilderbrandtii* relative to other landcover classification in the 3 counties in 2024.

Table 1. Land use and land cover classification area in ha for Imaroro and Mashuuru sub-locations between 2019 and 2024.

Class ID	Land use class	2019	2024	LULC
1	Grasslands	3430.7	5012.5	46%
2	<i>Ipomoea</i>	6602.4	8316.2	26%
3	Croplands	5063.0	4111.4	-19%
4	Built-up areas	37.0	43.1	16%
5	Water	623.6	697.1	12%
6	Bare land	87.3	124.3	43%
7	Woody vegetation	16406.9	11204.6	-32%
8	Other herbaceous vegetation	1555.9	4307.9	178%

3.1.1. Weed Presence, Number of Years in the Area and the Effect on Pasture

The percentage weed coverage in the region differs between the counties. In Kajiado, 79%, Makueni 35% and Taita Taveta 24% of the respondents reported presence of the weed on their farms (Table 2). The portion of land affected by the weed was indicated as more than half of the land by 75% of the respondents in Kajiado County while those of Makueni (84%) and Taita Taveta (98%) reported the weed to have affected less than a quarter of their land. The respondents in Kajiado indicated that the weed has been present in the county for a period of 30 years and 83% of the respondents reported that it completely hindered growth of any other

plant in areas it occurred. In Makueni, the presence of the weed was reported to be in the last 9 years while in Taita Taveta County it was indicated to be present in the last 3 years. Seventy-three percent in Makueni and 55% of the respondents in Makueni indicate that the weed had a slight effect on other plants with only 12% in Makueni and 6% in Taita Taveta indicating that the weed completely hinders the growth of other plants.

The weed distribution indicates that invasive weed needs urgent intervention to manage it in Kajiado counties as 83% of the respondents reported effect on growth of other plants. In Makueni and Taita Taveta counties the effects are much less but weed spared requires intervention to safeguard the livestock industry and wildlife.

Table 2. Knowledge of respondent on Ipomoea weed and its effects on pastureland.

No. of respondents (%); weed presence period in farm (years)			
Characteristic	KAJIADO, n = 354	MAKUENI, n = 366	T. TAVETA, n = 310
Reported Ipomoea presence on farm (% respondents)			
	79	35	24
Portion of land affected			
Less than quarter	5.6	84	98
Quarter to half	19	14	2
More than half	75	1	0
Years Ipomoea has been reported (Years)			
Mean (SD)	31 (15)	9 (13)	3 (8)
Reported Ipomoea effect on growth of grass			
Above 50% reduction	83	12	6
25% - 50% reduction	16	0	0
Reduction below 25%	1	73	59
No Effect	0	15	35

*Number in brackets is the standard deviation.

3.1.2. Soil Types and Topography Preferred by the Ipomoea Weed

About 91% of respondents reported that Ipomoea weed thrived in red soil, 57% in Makueni and 97% in Taita Taveta with most of the weed occurring on flat terrain than on steep slope (Table 3). This surface run off ability to carry seeds and deposit it on flat areas and areas along riverbeds was observed. The weed was reported to be concentrated along riverbanks, roadsides, ploughed and degraded land. Trucks transporting building sand spill the sand and seed on roadsides spreading the invasive weed.

Table 3. The type of soil and terrain preferred by *Ipomoea* weed.

	No. of respondents (%)			p-value ²
	KAJIADO, n = 354	MAKUENI, n = 366	Taita/Taveta, n = 310	
Soil type				<0.001
Black cotton soil	2	28	1	
Red soil	91	57	97	
Sandy soil	7	15	1.9	
Topography				<0.001
Flat area	96	68	95	
Sloppy areas	3.7	32	4.8	
Reported means of spread				<0.001
Riverbanks	24	26	25	
Degraded land	23	19	15	
Dumped Sand/Soil	6.8	1.3	6.2	
Ploughed land	24	21	22	
Roadsides spreading	22	28	31	

Table 4 indicates a widespread lack of community training on *Ipomoea* weed management across the three counties. Most respondents in Kajiado (97%), Makueni (100%), and Taita Taveta (98%) reported not receiving any training. Only 2.3% of respondents in both Kajiado and Taita Taveta received training, while no training was reported in Makueni. Institutional involvement was minimal, with the County Government (1.4%) and NYS (1.1%) cited in Kajiado, and World Vision (2.3%) in Taita Taveta. These findings underscore a significant gap in capacity-building efforts and limited institutional engagement in invasive species management.

Table 4. Capacity building of the communities on the management and control of *Ipomoea* weed and organizations involved.

Characteristic	No. of respondents (%)		
	Kajiado, N = 354 ¹	Makueni, N = 366 ¹	Taita/Taveta, N = 310 ¹
Received training	2.3	0	2.3
County government	1.4	0	0
None	97	100	98
NYS	1.1	0	0
World vision	0	0	2.3

3.2. Community Perceptions, and Effect of *I. hildebrandtii* on Herbage Plant Species

The data presented in **Table 5** illustrates significant disparities in livestock ownership across the three study sites—Kajiado, Makueni, and Taita Taveta. The respondents in Kajiado reported owning substantially more livestock compared to their counterparts in Makueni and Taita Taveta. The mean number of livestock per household in Kajiado was 132 (SD = 127), which is nearly ten times higher than in Makueni (mean = 14, SD = 9) and twelve times higher than in Taita Taveta (mean = 11, SD = 11). The total livestock recorded in Kajiado was 46,614, in stark contrast to 4978 in Makueni and 3351 in Taita Taveta. These differences were statistically significant ($p < 0.001$), underscoring the divergent livestock management systems and cultural-economic reliance on pastoralism among communities in these regions.

Table 5. Average number of livestock and livestock category owned per household in the study sites.

Item	Kajiado (n = 354)	Makueni (n = 366)	Taita Taveta (n = 310)	P ¹
Average number of Livestock per HH				
Mean (SD)	132 (127)	14 (9)	11 (11)	<0.001
Range	0 - 772	0 - 44	0 - 62	
Livestock category for each HH				
Cattle	34 (36)	3 (3)	3 (4)	<0.001
Goat	59 (70)	6 (5)	6 (8)	<0.001
Sheep	36 (43)	3 (3)	1 (3)	<0.001
Donkeys	2.15 (2.5)	0.85 (1.3)	0.56 (1.2)	<0.001

*Standard deviation in brackets; HH is household.

The range of livestock owned further highlights the variation in herd sizes, with Kajiado ranging from 0 to 772 animals per household, compared to much narrower ranges in Makueni (0 - 44) and Taita Taveta (0 - 62). This pattern reflects the predominantly pastoral livelihood system in Kajiado, where large herds are common due to both cultural and economic imperatives, in contrast to the more agro-pastoral or mixed farming systems in the other two counties. In terms of specific livestock categories, Kajiado also exhibited higher mean ownership across all types. On average, individuals in Kajiado owned 34 cattle (SD = 36), 59 goats (SD = 70), and 36 sheep (SD = 43), while those in Makueni

owned only 3 cattle, 6 goats, and 3 sheep. Similarly, in Taita Taveta, respondents reported mean ownership of 3 cattle, 6 goats, and 1 sheep, respectively. Donkey ownership followed a similar pattern, with Kajiado reporting a higher mean (2.15, SD = 2.5) compared to Makueni (0.85, SD = 1.3) and Taita Taveta (0.56, SD = 1.2). All differences across livestock categories were statistically significant ($p < 0.001$).

The data presented in **Table 6** outline the key factors limiting livestock production across the three study sites—Kajiado, Makueni, and Taita Taveta. These constraints reflect both environmental and socio-economic challenges, with notable variation in how they are prioritized by communities in different locations. Animal diseases emerged as a significant limiting factor, particularly in Taita Taveta (31%) compared to Makueni (21%) and Kajiado (19%). The higher percentage in Taita Taveta may reflect greater vulnerability due to limited veterinary services, poor disease surveillance, or environmental conditions favoring pathogen transmission. The differences across counties were statistically significant ($p < 0.001$), indicating that disease management is a critical area for intervention, especially in Taita Taveta.

Table 6. Factors limiting livestock production in study sites.

	Kajiado n = 354	Makueni n = 366	Taita Taveta n = 310	p-value ¹
Animal diseases	19	21	31	<0.001
Drinking water	18	24	25	
<i>Ipomoea</i> weed	31	10	3	
Productions skills	2	11	5	
Access to markets	3	12	8	
Pasture availability	26	22	28	

Water availability was reported as a constraint by 18% of respondents in Kajiado, 24% in Makueni, and 25% in Taita Taveta. The relatively uniform distribution of this limitation across sites highlights the pervasive nature of water scarcity in semi-arid and arid regions of Kenya. Given that livestock production is highly dependent on consistent access to water for both animals and forage growth, any fluctuations in water availability significantly impact herd health and productivity. The invasive *I. hildebrandtii* weed was identified as a major constraint in Kajiado (31%), with significantly lower reports in Makueni (10%) and Taita Taveta (3%). This finding reinforces earlier data suggesting that Kajiado is more heavily infested with *Ipomoea*, likely due to its larger livestock population and more extensive rangeland use, which may facilitate the spread and establishment of invasive species. The impact of *Ipomoea* is particularly detrimental in Kajiado, where

it competes directly with native forage species, reducing pasture quality and availability.

Production skills and access to markets were cited as limitations by smaller proportions of respondents. Only 2% in Kajiado reported lack of production skills as a barrier, compared to 11% in Makueni and 5% in Taita Taveta. This suggests that Makueni communities may require more capacity-building efforts in livestock husbandry, nutrition, and animal health management. Similarly, limited access to markets was more prevalent in Makueni (12%) and Taita Taveta (8%) than in Kajiado (3%), pointing to infrastructural and logistical challenges that hinder commercialization and income generation from livestock products in the former counties. Pasture availability was another common constraint, reported by 26% of respondents in Kajiado, 22% in Makueni, and 28% in Taita Taveta. The relatively high percentages reflect the overarching issue of rangeland degradation, seasonal variability, and invasive species encroachment, all of which reduce the quantity and quality of forage accessible to livestock.

Table 7 illustrates the perceived dispersal mechanisms of *I. hildebrandtii* across Kajiado, Makueni, and Taita Taveta counties, offering valuable insight into community-level understanding of the weed's spread. The data reveal both common and site-specific drivers of dispersal, with statistically significant differences observed, particularly in intentional planting as flowers and animal-mediated spread ($p < 0.001$). Runoff and sand movement emerged as the two most cited mechanisms across all three counties. Runoff was reported by 33% of respondents in Kajiado, 29% in Makueni, and 31% in Taita Taveta, while sand movement accounted for 30%, 34%, and 29% respectively (**Figure 5**). These results underscore the strong role of water and soil erosion processes in facilitating the spread of *I. hildebrandtii*, especially during rainy seasons or in areas with bare soil and degraded vegetation cover. This is consistent with the plant's ability to thrive in disturbed habitats and capitalize on hydrological flows for seed dispersal.

Table 7. Dispersal mechanism of *I. hildebrandtii* weed in the study sites.

Dispersal mechanism	No. of respondents (%)			p-value
	Kajiado n = 354	Makueni n = 366	Taita Taveta n = 310	
Planting as flowers/ornamental	6.3	3.7	2	<0.001
Sand Movement	30	34	29	
Run off	33	29	31	
Spread by Animals	3.6	16	20	
Wind Dispersal	27	17	18	

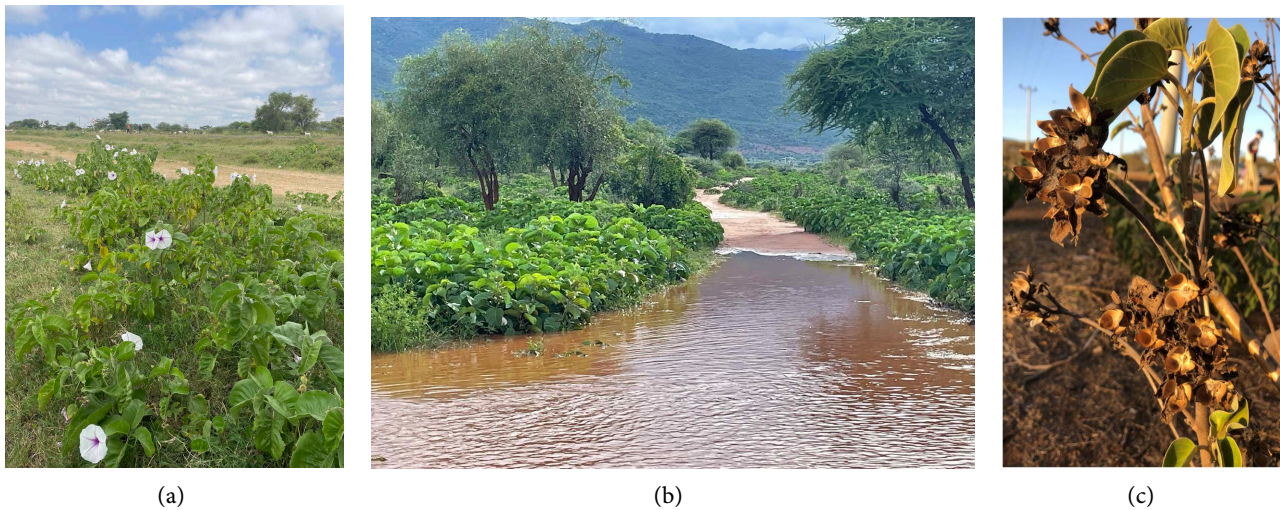


Figure 5. (a) Roadside weed growth, (b) Surface run off weed spread, (c) Seed shattering wind spread.

Wind dispersal was also frequently reported, particularly in Kajiado (27%), followed by Taita Taveta (18%) and Makueni (17%). This suggests that *I. hildebrandtii* likely produces lightweight seeds or vegetative parts capable of being transported by wind—a common trait among invasive species that enhances their capacity to colonize new areas, especially in open rangeland systems with minimal canopy cover. Interestingly, the spread by animals was markedly higher in Makueni (16%) and Taita Taveta (20%) compared to only 3.6% in Kajiado. This could be due to more frequent movement of livestock across weed-infested areas in these counties or differences in grazing patterns and herd mobility. The ingestion and excretion of viable seeds or physical transport via fur and hooves are potential vectors that may explain this mode of dispersal. These dynamics highlight the need for integrated management approaches that consider both ecological and livestock management dimensions.

A small proportion of respondents attributed the spread to intentional planting as ornamental flowers, particularly in Kajiado (6.3%) and to a lesser extent in Makueni (3.7%) and Taita Taveta (2%). While the percentage is relatively low, it raises critical concerns about the lack of awareness regarding the invasive nature of *I. hildebrandtii*, especially if its aesthetic value leads to deliberate propagation in homesteads or public spaces.

Table 8 presents community perceptions of the effects of *I. hildebrandtii* consumption by livestock across Kajiado, Makueni, and Taita Taveta counties, highlighting significant spatial differences in reported impacts ($p < 0.001$). These findings offer critical insight into the health risks posed by this invasive species to pastoral livelihoods and reinforce the urgency for effective control and mitigation strategies. The most severe effect—livestock death—was reported exclusively in Kajiado (2.1%) and not observed in Makueni or Taita Taveta. This suggests possible differences in plant toxicity levels, ingestion quantities, or susceptibility among livestock species in the region. Kajiado's higher livestock densities and reliance on

open grazing systems may increase exposure to large infestations of the plant, thereby elevating the risk of lethal ingestion.

Diarrhea and illnesses were the most commonly reported effects across all sites, with notable differences in their prevalence. Diarrhea was most reported in Kajiado (37%), followed by Makueni (15%) and Taita Taveta (5.6%). This suggests a stronger gastrointestinal response to the weed in Kajiado, potentially due to differences in plant phenology, grazing patterns, or drought-induced fodder shortages that force animals to consume unpalatable species. Conversely, general illness, which includes signs of weakness, weight loss, and loss of appetite, was highly reported in Taita Taveta (82%) and Makueni (63%), compared to 33% in Kajiado. This pattern implies that while acute responses like diarrhea may be more visible in Kajiado, chronic health issues may be more prominent in the other two counties, possibly due to longer-term low-level exposure to the weed or differences in herd management and veterinary care access.

Irritation, possibly involving oral or gastrointestinal inflammation, was reported by 15% of respondents in Kajiado, 20% in Makueni, and 10% in Taita Taveta. These values, though less prominent than other effects, still indicate widespread discomfort experienced by livestock upon consuming the plant. A small percentage of respondents reported no observable effect, primarily in Kajiado (13%) with minimal responses from Makueni (2%) and Taita Taveta (1.6%). This might reflect either genuine tolerance among certain animals or underreporting due to limited knowledge or observation. It is also possible that some livestock consume the plant in small, subclinical quantities not sufficient to induce observable symptoms.

Table 8. The effect of *I. hildebrandtii* plant when consumed by livestock in the study sites.

No. of respondents (%)	Kajiado n = 354	Makueni n = 366	Taita Taveta n = 310	p-value
Death	2.1	0	0	<0.001
Diarrhea	37	15	5.6	
Illnesses	33	63	82	
Irritation	15	20	10	
No observed effect	13	2	1.6	

3.3. Existing Control Interventions for *I. hildebrandtii*

The most prominent control method across all three regions is cutting and uprooting, with adoption rates of 70% in Kajiado, 72% in Makueni, and 89% in Taita Taveta (**Table 9**). While this method is labor-intensive, it may be the most accessible for communities lacking resources for other control techniques. The use of burning as a control strategy is notably lower, with only 29% of respondents in Kajiado, 21% in Makueni, and 7.3% in Taita Taveta reporting its application. The

lower prevalence of this method suggests several limitations associated with burning as a control technique.

Table 9. The control strategies *I. hildebrandtii* for applied by communities in study sites.

Characteristic (control method)	Kajiado, n = 354	Makueni, n = 366	Taita-Taveta, n = 310
Burning	194 (29%)	150 (21%)	27 (7.3%)
Chemical Herbicides	8 (1.2%)	4 (0.6%)	5 (1.4%)
Cutting and Uprooting	470 (70%)	508 (72%)	328 (89%)
Mechanically Using Machines	4 (0.6%)	4 (0.6%)	2 (0.5%)
No Control	0 (0%)	35 (5.0%)	7 (1.9%)
	n (%)		

The application of chemical herbicides is reported at a minimal rate, with only 1.2% in Kajiado, 0.6% in Makueni, and 1.4% in Taita Taveta adopting this approach. The low uptake of chemical herbicides suggests that this method may be less favorable for several reasons. First, the cost of herbicides may be prohibitive for many local farmers, particularly in rural areas where resources are scarce. The use of mechanically operated machines for control is minimal across the three study sites, with only 0.6% in Kajiado, 0.6% in Makueni, and 0.5% in Taita Taveta. The limited application of mechanical control suggests that machinery, while potentially effective for large-scale operations, is not widely accessible due to high capital costs, the need for specialized skills, and the absence of appropriate infrastructure in rural areas.

A small percentage of the population in Makueni (5%) and Taita Taveta (1.9%) report no control measures for *I. hildebrandtii*. The lack of control could be attributed to several factors, including limited awareness of the species' invasive nature, low perceived impact, or insufficient knowledge about available control methods. In some cases, communities may not recognize *I. hildebrandtii* as a significant threat or may be reluctant to invest time and resources into managing it if they perceive the problem as manageable through other means, such as natural processes.

One of the most significant limitations reported across all regions is the labor intensity and high cost of control measures, with Kajiado showing the highest proportion at 92%, followed by Makueni at 53% and Taita-Taveta at 57% (**Table 10**). The lack of information and training is another notable limitation in the control of *I. hildebrandtii*, particularly in Makueni, where 21% of respondents report this as a barrier. Kajiado (5.4%) and Taita-Taveta (16%) show lower percentages, but the issue is still present. A small proportion of respondents reported no limitations to control methods, with Makueni at 5.6% and Taita-Taveta at 0.6%. These results suggest that, in some instances, communities may feel that the current con-

trol methods are effective or that the limitations do not significantly impact their ability to manage the invasive species.

Table 10. Limitations to existing control interventions for *Ipomoea* weed in the study areas.

Current limitation to weed intervention	Kajiado, n = 354	Makueni, n = 366	Taita-Taveta, n = 310
Labor Intensive & High Cost	327 (92%)	393 (53%)	272 (57%)
Lack Information & Training	19 (5.4%)	154 (21%)	77 (16%)
No Limitation	0 (0%)	41 (5.6%)	3 (0.6%)
Quick Regenerative Power	5 (1.4%)	0 (0%)	0 (0%)
Spread from Neighboring Farms	3 (0.8%)	150 (20%)	128 (27%)
	n (%)		

The limitation of quick regenerative power of *I. hildebrandtii* was reported in only Kajiado (1.4%), indicating that the species' ability to regenerate rapidly is not a major concern in most regions. The issue of spreading from neighboring farms is a significant limitation, particularly in Taita-Taveta (27%) and Makueni (20%). In Kajiado, only 0.8% of respondents reported this as a challenge. The spread of this weed from neighboring farms highlights the connection of land management and the need for collective action for the invasive species.

The data in **Table 11** presents the percentage of respondents from Kajiado, Makueni, and Taita-Taveta counties who employed various control methods to manage the invasive species *I. hildebrandtii*. The responses reflect region-specific preferences, capacities, and environmental contexts, and offer key insights into community-based weed management practices. The associated p-value (<0.001) for burning indicates a statistically significant difference in the use of this method across the three counties. Cutting and uprooting emerges as the most widely adopted method across all sites, reported by 70% of respondents in Kajiado, 72% in Makueni, and 89% in Taita-Taveta. This approach is labor-intensive but accessible, particularly where financial or technological resources are limited.

Table 11. Control methods used by the communities in the management of the *I. hildebrandtii* weed in the study sites.

Applied control methods	% number of respondents			p-value
	Kajiado n = 354	Makueni n = 366	Taita-Taveta n = 310	
Burning	29	21	7.3	<0.001
Chemical herbicides	1.2	0.6	1.4	
Cutting and uprooting	70	72	89	
Ploughing in	0.6	5.6	2.4	

4. Discussion

There was a statistically significant variation ($p < 0.001$) in the control methods employed against *I. hildebrandtii* across the three counties. Burning was more prevalent in Kajiado (29%), while Taita Taveta heavily relied on manual methods such as uprooting and slashing (89%). These findings reflect underlying differences in land use, with pastoral systems in Kajiado relying on traditional fire use to manage expansive rangelands—a practice well-documented by [47] in East African drylands. In contrast, the preference for mechanical methods in Taita Taveta aligns with smaller-scale farming systems where manual labor is feasible. These disparities highlight the influence of socio-ecological context on weed management strategies, consistent with [48], who emphasized that control practices are often shaped by land tenure, labor availability, and awareness levels.

The occurrence of the weed seems to be spreading from Kajiado towards Makueni and Taita Taveta counties. The spread is believed to be influenced by human activity and weather. This agrees with [49] who pointed out that frequent droughts and rainfall events also cause changes in vegetation attributes and weed has been present since 1960s only that infestation is on the rise [50]. Significant differences were observed in perceived barriers to controlling *I. hildebrandtii* ($p < 0.001$). In Kajiado, 92% of respondents cited high labor and cost requirements, compared to 53% and 57% in Makueni and Taita Taveta respectively. This reflects the challenges of addressing infestations over large communal landscapes with limited mechanization and labor capacity. The findings reinforce assertions by [51] and [52], who noted that resource constraints remain a major limitation to invasive species management in rangelands, often resulting in delayed or partial control responses that allow the species to spread further.

There were highly significant differences in livestock ownership across the counties ($p < 0.001$), with Kajiado households owning markedly more livestock (mean = 132) than those in Makueni (14) and Taita Taveta (11). This aligns with the livelihood structure, as Kajiado is predominantly pastoral, while the other counties lean toward agro-pastoralism or mixed farming. Large herd sizes, while economically advantageous, increase exposure to invasive species in open grazing systems, particularly in degraded rangelands where native forage is scarce [53].

Counties differed significantly ($p < 0.001$) in the prevalence of livestock deaths and diarrhea attributed to *Ipomoea* exposure. Kajiado reported the highest levels of both livestock mortality (2.1%) and diarrhea (37%). This suggests a strong relationship between infestation levels and animal health impacts, particularly in counties where dependence on natural pastures is high. The toxicity of related *Ipomoea* species has been well-established [54], and symptoms such as diarrhea and death point toward chronic exposure to toxic alkaloids in contaminated grazing areas. These results stress the urgent need for integrated rangeland and veterinary interventions.

Dispersal pathways for *I. hildebrandtii* also differed significantly ($p < 0.001$).

The use of the plant as an ornamental was more common in Kajiado, suggesting a possible initial introduction vector and a lack of awareness about its invasiveness. Water runoff and wind (sand movement) were cited across all counties, confirming the weed's capacity for long-distance spread via abiotic means. Such findings align with the work of [55], who highlighted human-mediated and environmental vectors as primary drivers of invasive plant establishments in arid regions. The significantly higher reports of ornamental use in Kajiado may reflect localized introduction, requiring targeted awareness and behavioral change interventions.

Kajiado respondents were significantly more likely ($p < 0.001$) to perceive *I. hildebrandtii* as a constraint to livestock production (31%) compared to Makueni (10%) and Taita Taveta (3%). This perception correlates with the county's high livestock dependency and larger infestations. [56] similarly observed that invasive plants reduce the quantity and quality of available forage, compromising animal nutrition and leading to increased disease susceptibility. This finding further justifies the prioritization of invasive species control as part of rangeland and livestock development programs.

5. Conclusion and Recommendations

This study provides strong evidence of the socio-ecological impacts of *I. hildebrandtii* invasion across pastoralist and agro-pastoralist systems in southern Kenya. Statistically significant differences were observed in weed control methods, barriers to management, livestock ownership, morbidity and mortality cases linked to *I. hildebrandtii*, and dispersal pathways. Kajiado County, a primarily pastoral system, reported the highest infestation rates and associated livestock health risks. To have achieved successful stab at controlling the weed, it is critical that the pastoralists in the region have the skill and knowledge to manage the weed. For sustainability, capacity building of the communities should be built on county government in partnership with non-government organization. This is also anchored in local leadership to instill responsibility as effective management will need to get full support from local teams. In discovering the current technology and innovation, there is need for a linkage with research, extension and extension teams from universities and institutions of learning as well as policy makers. With cooperation with research organizations, county government and community leadership invasive weed will be managed and introduction to new field reduced to achieve optimal productivity of rangeland.

The findings highlight the urgent need for context-specific, sustainable invasive species management strategies to protect rangeland productivity, livestock health, and rural livelihoods. The study recommends the following:

- 1) Due to variation in control practices and resource availability, tailored approaches should be developed for each county.
- 2) Awareness campaigns should be launched to educate communities, especially in Kajiado, on the risks of using *I. hildebrandtii* ornamentally and to pro-

mote early reporting of new infestations.

3) Given the link between *I. hildebrandtii* and livestock health problems, interventions should combine weed control with veterinary outreach and pasture improvement to reduce animal exposure and improve forage quality.

4) Further research should focus on identifying potential biological control agents and understanding *I. hildebrandtii*'s ecological preferences to guide more effective interventions.

5) Counties should incorporate invasive species management into their rangeland and environmental conservation policies, and resource mobilization should be enhanced for long-term control.

Author Contributions

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Data Availability Statement

The data supporting the findings of this study will be made available upon reasonable request. GIS and remote sensing datasets used for mapping *I. hildebrandtii* will be accessible through institutional repositories or upon request from the corresponding author. Community perception data collected through surveys and focus group discussions will be provided in anonymized form to protect respondent confidentiality.

Conflicts of Interest

There is no conflict of interest with regard to the publication of this manuscript.

References

- [1] Zerga, B. (2015) Rangeland Degradation and Restoration: A Global Perspective. <https://api.semanticscholar.org/CorpusID:91181377>
- [2] Nash, D.J., Middleton, N. and Thomas, D. (1999) World Atlas of Desertification. *The Geographical Journal*, **165**, Article 325. <https://doi.org/10.2307/3060449>
- [3] Liebig, M.A., Gross, J.R., Kronberg, S.L., Hanson, J.D., Frank, A.B. and Phillips, R.L. (2006) Soil Response to Long-Term Grazing in the Northern Great Plains of North America. *Agriculture, Ecosystems & Environment*, **115**, 270-276. <https://doi.org/10.1016/j.agee.2005.12.015>
- [4] Alkemade, R., Reid, R.S., van den Berg, M., de Leeuw, J. and Jeuken, M. (2012) Assessing the Impacts of Livestock Production on Biodiversity in Rangeland Ecosystems.

- tems. *Proceedings of the National Academy of Sciences*, **110**, 20900-20905.
<https://doi.org/10.1073/pnas.1011013108>
- [5] Dean, C., Wardell-Johnson, G.W. and Harper, R.J. (2012) Carbon Management of Commercial Rangelands in Australia: Major Pools and Fluxes. *Agriculture, Ecosystems & Environment*, **148**, 44-64. <https://doi.org/10.1016/j.agee.2011.11.011>
- [6] Guerin, G.R., Sparrow, B., Tokmakoff, A., Smyth, A., Leitch, E., Baruch, Z., *et al.* (2017) Opportunities for Integrated Ecological Analysis across Inland Australia with Standardised Data from Ausplots Rangelands. *PLOS ONE*, **12**, e0170137.
<https://doi.org/10.1371/journal.pone.0170137>
- [7] Sobecki, T., Moffitt, D., Stone, J. and Franks, C. (2000) A Broad-Scale Perspective on the Extent, Distribution, and Characteristics of US Grazing Lands and AG Mendenhall. The Potential of US Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. CRC Press, 51-94.
- [8] Miller, D. (2002) Sixth in a Series: The Importance of China's Nomads. *Rangelands*, **24**, 22-24. https://doi.org/10.2458/azu_rangelands_v24i1_miller
- [9] Nalule, A. (2010) Social Management of Rangelands and Settlement in Karamoja Subregion. *Journal of Food Security*, **4**, 68-75.
- [10] Mwilawa, A.J., Komwihangilo, D.M. and Kusekwa, M.L. (2008) Conservation of Forage Resources for Increasing Livestock Production in Traditional Forage Reserves in Tanzania. *African Journal of Ecology*, **46**, 85-89.
<https://doi.org/10.1111/j.1365-2028.2008.00934.x>
- [11] Rija, A., Kideghesho, J., Mwamende, K. and Selemani, I. (2013) Emerging Issues and Challenges in Conservation of Biodiversity in the Rangelands of Tanzania. *Nature Conservation*, **6**, 1-29. <https://doi.org/10.3897/natureconservation.6.5407>
- [12] Awgachew, S., Flintan, F. and Bekure, S. (2015) Participatory Rangeland Management Planning and Its Implementation in Ethiopia. <https://hdl.handle.net/10568/67916>
- [13] Opiyo, F., Ekaya, W., Nyariki, D. and Mureithi, S.M. (2011) Seedbed Preparation Influence on Morphomeric Characteristics of Perennial Grasses of a Semi-Arid Rangeland in Kenya. *African Journal of Plant Science*, **5**, 460-486.
- [14] Nyariki, D.M. and Amwata, D.A. (2019) The Value of Pastoralism in Kenya: Application of Total Economic Value Approach. *Pastoralism*, **9**, Article No. 9.
<https://doi.org/10.1186/s13570-019-0144-x>
- [15] Asner, G.P., Elmore, A.J., Olander, L.P., Martin, R.E. and Harris, A.T. (2004) Grazing Systems, Ecosystem Responses, and Global Change. *Annual Review of Environment and Resources*, **29**, 261-299.
<https://doi.org/10.1146/annurev.energy.29.062403.102142>
- [16] Kassahun, A., Snyman, H.A. and Smit, G.N. (2008) Impact of Rangeland Degradation on the Pastoral Production Systems, Livelihoods and Perceptions of the Somali Pastoralists in Eastern Ethiopia. *Journal of Arid Environments*, **72**, 1265-1281.
<https://doi.org/10.1016/j.jaridenv.2008.01.002>
- [17] Cameron, D.R., Marty, J. and Holland, R.F. (2014) Whither the Rangeland?: Protection and Conversion in California's Rangeland Ecosystems. *PLOS ONE*, **9**, e103468.
<https://doi.org/10.1371/journal.pone.0103468>
- [18] Hoffmann, B.D. and James, C.D. (2010) Using Ants to Manage Sustainable Grazing: Dynamics of Ant Faunas along Sheep Grazing Gradients Conform to Four Global Patterns. *Austral Ecology*, **36**, 698-708.
<https://doi.org/10.1111/j.1442-9993.2010.02205.x>
- [19] Odero, W.J.A. (2017) Smallholder Dairy Production in Kenya; A Review. Livestock

- Research for Rural Development, 29.
- [20] FAO (2009) Review of Evidence on Drylands Pastoral Systems and Climate Change: Implications and Opportunities for Mitigation and Adaption. Food and Agriculture Organization of the United Nations.
- [21] Akuja, T.E. and Kandagor, J. (2019) A Review of Policies and Agricultural Productivity in the Arid and Semi-Arid Lands (ASALS), Kenya: The Case of Turkana County. *Journal of Applied Biosciences*, **140**, Article 14304. <https://doi.org/10.4314/jab.v140i1.9>
- [22] Soussana, J.F., Allard, V., Pilegaard, K., Ambus, P., Amman, C., Campbell, C., *et al.* (2007) Full Accounting of the Greenhouse Gas (CO₂, N₂O, CH₄) Budget of Nine European Grassland Sites. *Agriculture, Ecosystems & Environment*, **121**, 121-134. <https://doi.org/10.1016/j.agee.2006.12.022>
- [23] Angerer, J.P., Fox, W.E., Wolfe, J.E., Tolleson, D.R. and Owen, T. (2023) Land Degradation in Rangeland Ecosystems. In: Sivanpillai, R., Ed., *Biological and Environmental Hazards, Risks, and Disasters*, Elsevier, 395-434. <https://doi.org/10.1016/b978-0-12-820509-9.00007-1>
- [24] Witt, A., Beale, T. and van Wilgen, B.W. (2018) An Assessment of the Distribution and Potential Ecological Impacts of Invasive Alien Plant Species in Eastern Africa. *Transactions of the Royal Society of South Africa*, **73**, 217-236. <https://doi.org/10.1080/0035919x.2018.1529003>
- [25] Shackleton, R.T., Shackleton, C.M. and Kull, C.A. (2019) The Role of Invasive Alien Species in Shaping Local Livelihoods and Human Well-Being: A Review. *Journal of Environmental Management*, **229**, 145-157. <https://doi.org/10.1016/j.jenvman.2018.05.007>
- [26] Macharia, P.N. (2004) Community Based Interventions as a Strategy to Combat Desertification in the Arid and Semi-Arid Rangelands of Kajiado District, Kenya. *Environmental Monitoring and Assessment*, **99**, 141-147. <https://doi.org/10.1007/s10661-004-4014-6>
- [27] Lusigi, W.J., Nkurunziza, E.R. and Masheti, S. (1984) Forage Preferences of Livestock in the Arid Lands of Northern Kenya. *Journal of Range Management*, **37**, Article 542. <https://doi.org/10.2307/3898855>
- [28] Mganga, K., Musimba, N., Nyariki, D., Nyangito, M., ombe, W., Ekaya, W., *et al.* (2010) The Challenges Posed by *Ipomoea kituensis* and the Grass-Weed Interaction in a Reseeded Semi-Arid Environment in Kenya. *International Journal of Current Rese*, **11**, 1-5.
- [29] Mworira, J.K. (2011) Invasive Plant Species and Biomass Production in Savannas. In: Atazadeh, I., Ed., *Biomass and Remote Sensing of Biomass*. IntechOpen.
- [30] Kisambo, B.K., Ogillo, B.P. and Musyimi, D. (2023) Effects of Weed Control Methods on Weeds and Productivity of Range Grasses in Semi-Arid Kenya. *Tropical and Subtropical Agroecosystems*, **26**, 1-13. <https://doi.org/10.56369/tsaes.4494>
- [31] Emerton, L. and Howard, G. (2008) A Toolkit for the Economic Analysis of Invasive Species. Global Invasive Species Programme, CABI/IUCN.
- [32] Manyeki, J., Kubasu, D., Kirwa, E. and Mnene, W. (2013) Assessment of Socioeconomic Factors Influencing Adoption of Natural Pastures Improvement Technologies in Arid and Semi-Arid Lands of Kenya. *Livestock Research for Rural Development*, 25.
- [33] Manyeki, J., Kirwa, E., Ogillo, B., Mnene, W., Kimitei, R., Mosu, A., *et al.* (2015) Economic Analysis of Natural Pasture Rehabilitation through Reseeding in the South-

- ern Rangelands of Kenya. *Livestock Research for Rural Development*, 27.
- [34] Lugusa, K. (2015) Fodder Production as an Adaptation Strategy in the Drylands: A Case Study of Producer Groups in Baringo County, Kenya. <https://doi.org/10.13140/RG.2.1.3027.3363>
- [35] Erick, O., Wasonga, O., Wasonga, Elhadi, M. and Elhadi, Y. (2017) Analysis of Fodder Production and Marketing in the Rangelands of Southern Kenya. <https://www.researchgate.net/publication/321419540>
- [36] Ogutu, J.O., Piepho, H., Said, M.Y. and Kifugo, S.C. (2014) Herbivore Dynamics and Range Contraction in Kajiado County Kenya: Climate and Land Use Changes, Population Pressures, Governance, Policy and Human-Wildlife Conflicts. *The Open Ecology Journal*, 7, 9-31. <https://doi.org/10.2174/1874213001407010009>
- [37] Mganga, K.Z., Musimba, N.K.R., Nyariki, D.M., Nyangito, M.M. and Mwang'ombe, A.W. (2013) The Choice of Grass Species to Combat Desertification in Semi-Arid Kenyan Rangelands Is Greatly Influenced by Their Forage Value for Livestock. *Grass and Forage Science*, 70, 161-167. <https://doi.org/10.1111/gfs.12089>
- [38] Gikaba, J.M., Muthoni, K.S. and Bebe, B.O. (2014) Influence of Drought Duration on Livestock Feeding Practices by Maasai Pastoralists in Kajiado County, Kenya. *International Journal of Innovation and Applied Studies*, 8, 225-31.
- [39] Amwata, D.A., Nyariki, D.M. and Musimba, N.R.K. (2015) Factors Influencing Pastoral and Agropastoral Household Vulnerability to Food Insecurity in the Drylands of Kenya: A Case Study of Kajiado and Makueni Counties. *Journal of International Development*, 28, 771-787. <https://doi.org/10.1002/jid.3123>
- [40] Moss, C.J. (2001) The Demography of an African Elephant (*Loxodonta Africana*) Population in Amboseli, Kenya. *Journal of Zoology*, 255, 145-156. <https://doi.org/10.1017/s0952836901001212>
- [41] Government of Makueni County (2013) First Integrated Development [Internet].
- [42] Aizen, M.A., Morales, C.L. and Morales, J.M. (2008) Invasive Mutualists Erode Native Pollination Webs. *PLOS Biology*, 6, e31. <https://doi.org/10.1371/journal.pbio.0060031>
- [43] Duncan, C.A., Jachetta, J.J., Brown, M.L., Carrithers, V.F., Clark, J.K., Ditomaso, J.M., *et al.* (2004) Assessing the Economic, Environmental, and Societal Losses from Invasive Plants on Rangeland and Wildlands. *Weed Technology*, 18, 1411-1416. [https://doi.org/10.1614/0890-037x\(2004\)018\[1411:ateas\]2.0.co;2](https://doi.org/10.1614/0890-037x(2004)018[1411:ateas]2.0.co;2)
- [44] Fisher, R.A. (1935) The Fiducial Argument in Statistical Inference. *Annals of Eugenics*, 6, 391-398. <https://doi.org/10.1111/j.1469-1809.1935.tb02120.x>
- [45] Mao, L., Kim, K. and Miao, X. (2021) Sample Size Formula for General Win Ratio Analysis. *Biometrics*, 78, 1257-1268. <https://doi.org/10.1111/biom.13501>
- [46] Greenwood, P.E. and Nikulin, M.S. (1996) A Guide to Chi Squared Testing. John Wiley & Sons.
- [47] Grillo, K. (2014) Pastoralism in Africa: Past, Present and Future. *Azania: Archaeological Research in Africa*, 49, 265-267. <https://doi.org/10.1080/0067270x.2014.903130>
- [48] Rejmánek, M. and Richardson, D.M. (2013) Trees and Shrubs as Invasive Alien Species—2013 Update of the Global Database. *Diversity and Distributions*, 19, 1093-1094. <https://doi.org/10.1111/ddi.12075>
- [49] Kedera, C. and Kuria, B. (2005) Invasive Alien Species in Kenya: Status and Management. *Proceedings of a Workshop*, Braunschweig, Germany, 22-26 September 2003, 26.

- [50] Macharia, P.N. and Ekaya, W.N. (2005) The Impact of Rangeland Condition and Trend to the Grazing Resources of a Semi-Arid Environment in Kenya. *Journal of Human Ecology*, **17**, 143-147. <https://doi.org/10.1080/09709274.2005.11905769>
- [51] Shackleton, R.T., Le Maitre, D.C., Pasiecznik, N.M. and Richardson, D.M. (2014) Prosopis: A Global Assessment of the Biogeography, Benefits, Impacts and Management of One of the World's Worst Woody Invasive Plant Taxa. *AoB PLANTS*, **6**, plu027. <https://doi.org/10.1093/aobpla/plu027>
- [52] Chikoye, D., Manyong, V.M. and Ekeleme, F. (2000) Characteristics of Speargrass (*Imperata cylindrica*) Dominated Fields in West Africa: Crops, Soil Properties, Farmer Perceptions and Management Strategies. *Crop Protection*, **19**, 481-487. [https://doi.org/10.1016/s0261-2194\(00\)00044-2](https://doi.org/10.1016/s0261-2194(00)00044-2)
- [53] Thornton, P.K., Kruska, R.L., Henninger, N., Kristjanson, P.M., Reid, R.S., Atieno, F., *et al.* (2002) Mapping Poverty and Livestock in the Developing World [Internet]. International Livestock Research Institute.
- [54] Pfister, J.A., Panter, K.E., Gardner, D.R., Stegelmeier, B.L., Ralphs, M.H., Molyneux, R.J., *et al.* (2001) Alkaloids as Anti-Quality Factors in Plants on Western U.S. Rangelands. *Journal of Range Management*, **54**, Article 447. <https://doi.org/10.2307/4003116>
- [55] Foxcroft, L.C., Rouget, M., Richardson, D.M. and Mac Fadyen, S. (2004) Reconstructing 50 Years of *Opuntia stricta* Invasion in the Kruger National Park, South Africa: Environmental Determinants and Propagule Pressure. *Diversity and Distributions*, **10**, 427-437. <https://doi.org/10.1111/j.1366-9516.2004.00117.x>
- [56] Agbeve, R., Tamatey, P., Owusu Sarkwa, F. and Timpong-Jones, E. (2021) A Review of the Impact of Invasive Species on Rangeland Productivity. *1st Joint GSAP & GASA Conference with the Theme "Sustainable Rearing for Food and Jobs in The Era of COVID-19: The Role of Stakeholders in The Animal Industry"*, Tamale, 24-27 August 2021, 522-533.