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Research Article

Adoption Patterns and Determinants of *Prosopis juliflora* Management Interventions Among Households in Baringo South Sub-county, Kenya

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Abstract

Prosopis juliflora is a highly invasive species in Kenya's semi-arid lands, presenting significant ecological threats while simultaneously offering potential livelihood opportunities. This study aimed to examine the adoption patterns and determinants of its management interventions by using a cross-sectional research design, collecting data from 270 households in Baringo South Sub-County through a multistage sampling technique. The data were analysed using descriptive statistics and a Generalized Poisson Regression Model (GPRM) to identify adoption patterns and assess the intensity of adoption of the *Prosopis juliflora* management interventions, respectively. The study findings reveal that the most prevalent management interventions are low-value options, dominated by charcoal production (84.85%) and firewood production (47.73%), whereas there is limited adoption of higher-value alternatives such as livestock feed processing (12.88%) and biochar production (5.68%). The regression analysis showed that adoption intensity is positively influenced by landholding size ($p<0.01$) and distance to the market ($p<0.01$), and on the contrary, it is negatively associated with household size, access to credit, casual labour occupation, training, access to information, and awareness of legal frameworks. These findings highlight a critical need for targeted interventions to promote sustainable and diversified *Prosopis juliflora* management. The study recommends implementing tailored training programs, enhancing market access for higher-value products, and establishing supportive policy frameworks to improve both ecological restoration and livelihood opportunities for local communities.

Keywords

Prosopis juliflora, Invasive Species Management, Adoption Patterns, Adoption Intensity, Baringo South, Kenya

1. Introduction

Invasive alien plant species (IAPS) are increasingly recognized as one of the greatest threats to biodiversity, agricultural productivity, and human well-being worldwide, with the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services reporting that there are more than 37,000 alien species globally [1], of which about 3,500 are invasive. The economic toll of biological invasions is immense, exceeding USD 423 billion annually, with costs rising fourfold each decade since 1970 [2], where plants are reported to account for about 6% of invasive alien species. While some

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of these invasive plants provide benefits such as fodder or erosion control, most disrupt ecosystems, diminish biodiversity, reduce crop yields, and impose high management costs. These impacts are particularly severe in developing regions, where livelihoods are highly dependent on natural resources and institutional capacity for invasive species control is limited.

In Africa, invasive plants such as *Lantana camara*, *Opuntia stricta*, *Chromolaena odorata*, and *Prosopis juliflora* have had profound ecological and economic consequences [3], and in East Africa, *Prosopis juliflora* stands out as one of the most widespread and problematic IAPS. Native to Central and South America, this tree species was introduced in the 1970s and 1980s to combat desertification, provide shade, and supply fuelwood in Kenya's arid and semi-arid lands (ASALs) [4, 5]. Its adaptability to poor soils, nitrogen-fixing ability, and drought resistance made it initially attractive, however, these same traits enabled it to become highly invasive. *Prosopis juliflora* has spread rapidly across Kenya's ASAL counties including Turkana, Isiolo, Tana River, and Baringo, forming dense thickets that displace native vegetation, reduce grazing areas, and disrupt hydrological systems [5-7].

In Baringo South Sub-County, *Prosopis juliflora* has expanded dramatically, besides, between 1988 and 2016, its coverage rose from 882 hectares to over 18,700 hectares, with an annual growth rate of nearly 4% [8], and around Lake Baringo, its spatial footprint increased more than 200-fold during the same period [9]. This expansion has imposed heavy ecological and socio-economic costs on agro-pastoral households: grazing lands have been lost, livestock productivity has declined, and pastoralists now face increased burdens of land clearing and adaptation. The plant's thorns injure people and animals, while its pods, when consumed, cause tooth decay, intestinal damage, and malnutrition in livestock. Hydrologically, its root systems block rivers and exacerbate siltation, worsening flooding and water scarcity [10].

While *Prosopis juliflora* causes serious ecological damage, it also provides potential livelihood opportunities, whereby households exploit it for charcoal, firewood, poles, and in some cases livestock feed or even beekeeping. Studies in Kenya show that households can earn significant income from its utilization, with charcoal sales alone fetching up to KES 3 million annually in some areas [11]. The plant also contributes positively to soil stabilization and nitrogen fixation.

Recognizing this duality, the Kenyan government and development agencies have shifted towards utilization-based management, which seeks to harness *Prosopis juliflora* for economic benefit while simultaneously controlling its spread. The Kenya Forestry Research Institute (KEFRI), Kenya Forest Service (KFS), and other NGOs have promoted interventions such as pod processing for livestock feed, biochar production, beekeeping, and land reclamation through reseeding and grass planting. Furthermore, the National Strategy and Action Plan for the Management and Control of *Prosopis juliflora* (2023–2032) reflects this shift by encouraging deliberate removal coupled with sustainable land management practices [12, 13].

These management approaches are expected to improve household livelihoods while simultaneously mitigating the negative environmental effects of *Prosopis juliflora*. However, the intensity of their adoption among households remains largely unquantified in Baringo South Sub-County.

This study, therefore, contributes to filling this gap by examining the adoption patterns and determinants of *Prosopis juliflora* management interventions among households in Baringo South Sub-County. Specifically, it sought to (i) characterize the type of management interventions adopted, and (ii) analyse the socio-economic and institutional factors influencing the intensity of adoption of these management interventions.

2. Materials and Methods

2.1. Study Area

The study was conducted in Baringo South Sub-County, Baringo County, Kenya, which is located between longitudes 35°50′E and 36°30′E and latitudes 0°10′N and 0°40′N (Figure 1). The area covers approximately 1,985 km², including 139.5 km² of surface water from Lake Bogoria and Lake Baringo [14], and lies within the Eastern Rift Valley, with altitudes ranging from 870 m in the lowlands to 2,499 m in the Tugen Hills [15]. The climate is semi-arid, characterized by agro-climatic zones IV and V, with mean annual rainfall of 300 – 700 mm in the lowlands and up to 1,500 mm in the highlands [16]. The area's vegetation comprises dryland woody species, notably *Prosopis juliflora*, which dominates the lowlands, alongside acacia species and grasslands. The communities are predominantly engaged in agro-pastoral livelihoods, supplemented by charcoal production, beekeeping, and tourism [17].

Baringo South Sub-County was purposively selected for this study since it is one of Kenya's areas most affected by *Prosopis juliflora*. Furthermore, the area's history of *Prosopis juliflora* management initiatives and diverse livelihoods makes it ideal for assessing the adoption patterns of the plant's management [18].

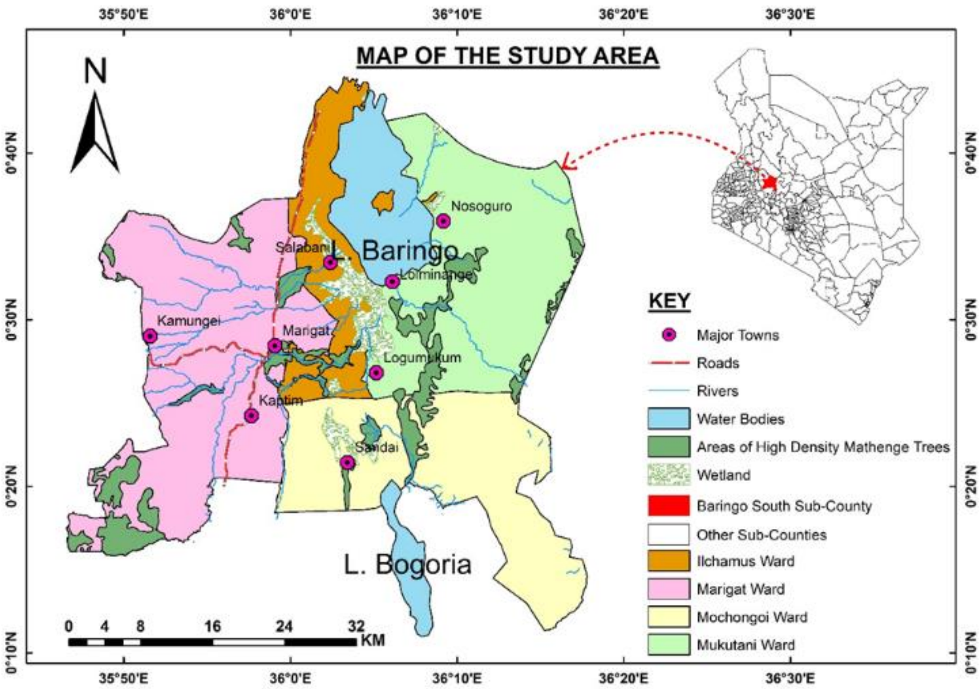

Figure 1. *Map of Baringo South Sub-County.*

2.2. Data Collection and Analysis

Primary data were collected using a household survey, in which a multi-stage sampling procedure was applied: Firstly, Baringo South Sub-County was purposively selected due to its high *Prosopis juliflora* infestation and concentration of management interventions [18]. Secondly, four administrative wards; Ilchamus, Mukutani, Marigat, and Mochongoi, were selected, and lastly, from each ward, households were randomly drawn. In total, 270 households were surveyed, proportionately allocated across the four wards [19].

Data were collected by trained enumerators fluent in local languages using semi-structured questionnaires administered face-to-face. The questionnaires captured household socio-economic characteristics, types of *Prosopis juliflora* management interventions adopted, and institutional factors, with responses recorded digitally using ODK Collect software for quality monitoring.

The data were analysed using STATA 17, where descriptive statistics (frequencies, percentages, means) and inferential tests (Chi-square, t-tests) were used to describe adoption patterns and compare them across household characteristics [20, 21]. Adoption intensity, defined as the number of management interventions adopted by a household, was modelled using a Generalized Poisson Regression Model (GPRM) to account for under-dispersion in the count data [22, 23]. Independent variables included socio-economic and institutional factors identified from literature and economic theory, and model performance was assessed using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC).

In the application of the GPRM, the response variable (Y= the number of *Prosopis juliflora* management interventions adopted) follows a Generalized Poisson distribution, which is an extension of the standard Poisson distribution [24]. The model theorizes that the response variable y_i is governed by the following Probability Mass Function (PMF):

$$f(y_i;\theta_i,\delta)=\frac{\theta_i(\theta_i+\delta y_i)^{y_i-1}e^{-\theta_i-\delta y_i}}{y_i!},y_i=0,1,2,\ldots \quad (1)$$

Where $\theta_i>0$ and max $(-1,-\theta_i/4)<\delta<1$ [25]. The mean and variance of the Generalized Poisson random variable are expressed as follows:

$$\mu_i=E(Y_i)=\frac{\theta_i}{1-\delta}, \quad (2)$$

$$\mathrm{Var}(Y_i)=\frac{\theta_i}{(1-\delta)^3}=\frac{1}{(1-\delta)^2}E(Y_i)=\phi E(Y_i) \quad (3)$$

The expression $1/(1-\delta)^2$ functions as a dispersion parameter, specifically, when δ equals 0, the distribution exhibits equi-dispersion, and the GPRM simplifies to the Standard Poisson distribution with mean θ_i. If δ is greater than 0, the model displays overdispersion, whereas a negative δ indicates under-dispersion [26].

The empirical model for implementing the GPRM was estimated as follows:

$$Adpintensty_i = \beta_0 + \beta_1 HHsize + \beta_2 Education + \beta_3 Age + \beta_4 Sex + \beta_5 HHincome + \beta_6 Credit + \beta_7 Grpmember + \beta_8 Distmarkt + \beta_9 Training + \beta_{10} Occupation + \beta_{11} Information + \beta_{12} Landsize + \beta_{13} Legalframework + \beta_{14} Technology + \mu_i \quad (4)$$

3. Results and Discussion

3.1. Adoption Patterns of *Prosopis juliflora* Management Interventions

The study reveals that adoption of *Prosopis juliflora* management interventions in Baringo South Sub-County is dominated by energy-related activities (Figure 2). Charcoal production is the most widely adopted intervention (84.85%), followed by firewood production (47.73%) and poles/posts production (29.92%). Other interventions include land reclamation (18.56%), livestock feed processing (12.88%), beekeeping (8.71%), biochar production (5.68%), and rope production (1.14%).

The predominance of charcoal and firewood production reflects their low entry barriers, availability of raw material, and high local demand, findings which are consistent with Mwalewa et al and Wakie et al [11, 27]. In contrast, low adoption of higher-value and ecologically beneficial practices such as livestock feed processing and biochar production can be attributed to technical complexity, higher capital requirements, and limited market access of these interventions [28].

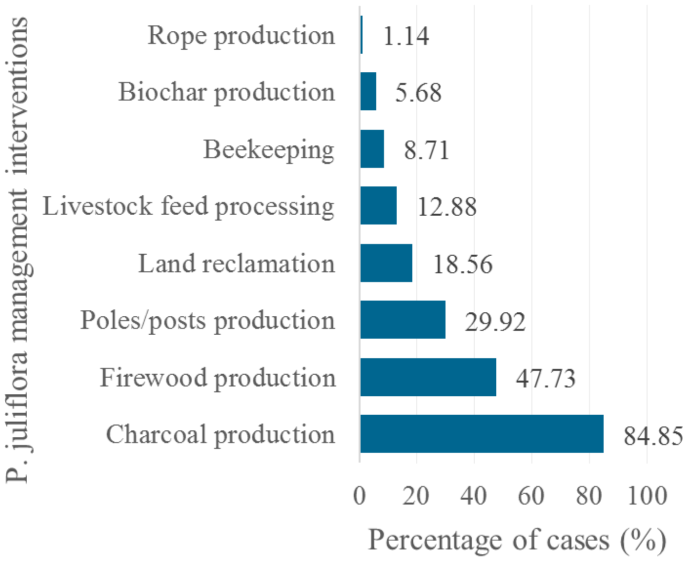

Figure 2. *Prosopis juliflora management interventions implemented in Baringo South Sub-County (N=264).*

3.2. Description and Descriptive Statistics of Variables Used in the Econometric Model

Table 1 presents the description and summary statistics of the variables included in the GPRM. On average, households adopted about two *Prosopis juliflora* management interventions, with considerable variation (Std. dev. = 1.19), highlighting differences in households' capacity and willingness to engage in multiple practices.

Table 1. *Description of variables used in the GPRM (N=263).*

Variable	Description	Mean	Std. Dev
Dependent variable			
Adoption intensity	Number of *Prosopis juliflora* management interventions adopted	2.03	1.19
Independent variables			
Sex	1 = Male, 0 = Female	1.34	0.47

Variable	Description	Mean	Std. Dev
Age	Age of household head (years)	42.42	11.40
Household size	Number of household members	4.94	2.64
Education	Level of education of household head (1 = None, 2 = Primary, 3 = Secondary, 4 = Tertiary)	2.81	0.79
Group membership	1 = Household head belongs to a group/community organization, 0 otherwise)	1.33	0.47
Training	1 = Household has received training on *Prosopis juliflora* management, 0 otherwise	1.35	0.48
Occupation	Main occupation of household head (1 = Unemployed, 2 = Agro-pastoralist, 3 = Salaried employment, 4 = Casual labour, 5 = Self-employed)	2.44	0.99
Credit access	1 = Household has access to credit, 0 otherwise)	1.24	0.43
Distance to market	Distance to nearest market (km)	10.5	10.00
Household income	Average monthly household income (KES)	17265.21	11679.06
Information access	1 = Household has access to information on *Prosopis juliflora* management, 0 otherwise	1.05	0.22
Landholding size	Total household landholding (acres)	4.02	2.66
Legal framework awareness	1 = Household aware of legal frameworks on *Prosopis juliflora* management, 0 otherwise	1.18	0.39
Technology	1 = Household has access to relevant technology, 0 otherwise	1.26	0.44

The average age of household heads was 42 years, suggesting that most respondents were in their economically active years [29], potentially indicating a greater likelihood of involvement in *Prosopis juliflora* management activities, whereas household size averaged nearly five members, which is above Kenya's national average of 3.8 [30]. Larger families may provide labour for labour-intensive interventions such as land reclamation [31], but they may also face competing demands on household resources, reducing per capita income and, consequently, diminishing participation in environmental or natural resource management [32].

In terms of gender, the majority of households were male-headed (66.16%), implying that male-headed households were more engaged in *Prosopis juliflora* management, likely due to the labour-intensive nature of activities such as cutting, clearing, and processing [13]. Occupation patterns showed that agro-pastoralism remained the primary livelihood for most households, reflecting their closer proximity to natural resources and greater exposure to land management interventions [33].

Education level averaged just under three on the scale used, implying that most household heads had attained at least primary to secondary education. This level of education is likely sufficient to facilitate the understanding and uptake of management information and innovations [34]. Group membership was relatively high, with 67.30% of the respondents reporting membership in civil society or community organizations, which enhances collective action and knowledge sharing [35].

Institutional support indicators, which often shape adoption patterns [36], revealed broad access among households, with about 64.64% of respondents reporting to have received training on *Prosopis juliflora* management, while 94.68% reported access to management information. Similarly, access to credit (76.05%), technology (73.76%), and awareness of legal frameworks (81.75%) were high.

The mean landholding size was about 4 acres, with considerable variation across households, implying that larger landowners are plausibly more motivated to adopt multiple interventions to safeguard productive land from encroachment [37]. Household monthly income averaged KES 17,265.21, reflecting modest income levels that may restrict the adoption of costly interventions such as livestock feed processing or biochar production [38], and lastly, the average distance to the nearest market was 10.5 km, which may shape adoption decisions by affecting input access, product marketing, and transaction costs [39].

3.3. Determinants of Adoption Intensity

Results from the GPRM (Table 2), reveal that several socio-economic and institutional factors significantly influence the intensity of *Prosopis juliflora* management adoption. The model estimates are presented as incidence rate ratios (IRRs), which, like odds ratios in logistic regression, indicate whether a factor increases (IRR > 1.0) or decreases (IRR < 1.0) the rate of adoption [40].

Occupation emerged as one of the determinants, where casual labourers were seen to adopt significantly fewer interventions than unemployed households (the reference category) (IRR = 0.76, $p < 0.05$), plausibly because their dependence on irregular, low-paying jobs limits both the time and resources available for sustained management. This finding echoes Eschen et al, who observed that households constrained by labour demands often underinvest in invasive species control [41]. Household size also had a negative influence (IRR = 0.95, $p < 0.01$), suggesting that larger families prioritize subsistence needs over environmental management. While Danso-Abbeam et al similarly reported reduced adoption among larger households [42], other studies e.g., Okumu, point to potential labour advantages [43], highlighting the contextual nature of household dynamics.

Table 2. *GPR model results on factors influencing the intensity of adoption of Prosopis juliflora management interventions (N=263).*

Variable		IRR	
Sex		1.00	
Age		1.00	
Education level – None		1.00	
Education level – Primary		1.01	
Education level – Secondary		1.06	
Education level – Tertiary		1.12	
Occupation – Unemployed		1.00	
Occupation – Agro-pastoralist		0.96	
Occupation – Salaried employment		0.82	
Occupation – Casual labour		0.76**	
Occupation – Self-employed/enterprise owner		0.89	
Household size		0.95***	
Household income		1.00	
Landholding size		1.04***	
Access to information on *Prosopis juliflora* management		0.77**	
Prosopis juliflora management training		0.81**	
Group membership		0.89	
Distance to market		1.03***	
Access to credit		0.81**	
Access to technology		1.11	
Aware of *Prosopis juliflora* management legal frameworks		0.75***	
_cons		5.00***	
/atanh delta	-0.50	Wald Chi2(19)	233.88
delta	-0.46	Prob > chi2	0.0000

Note: (***) and (**) denotes significance at 1% and 5% levels, respectively

Likelihood-ratio test of delta=0: chi2(1) = 77.36 Prob>=chi2 = 0.0000.

By contrast, landholding size was positively and significantly associated with adoption intensity (IRR = 1.04, $p < 0.01$), where larger landowners appeared more motivated to protect their farms from *Prosopis juliflora* encroachment, consistent with findings from Mzyece and Ng'ombe and Nyamweya, which link farm size to higher adoption of improved practices [44, 45]. Surprisingly, however, both access to information (IRR = 0.77, $p < 0.05$) and training (IRR = 0.81, $p < 0.05$) reduced adoption intensity. This counterintuitive result may reflect gaps in how extension services are delivered, where information is poorly targeted, not accompanied by follow-up support, or misaligned with local realities. Kamiri and Adoyo et al similarly highlight the limits of awareness creation when not embedded in practical, context-specific interventions [10, 46].

Institutional and market-related variables also played a role in influencing adoption intensity. Distance to market had a positive effect (IRR = 1.03, $p < 0.01$), possibly because remote households face more severe infestations and must rely on self-managed strategies, resonating with findings from Ohen et al, who noted that remoteness often shapes adaptation behaviour [47]. In contrast, access to credit reduced adoption intensity (IRR = 0.81, $p < 0.05$), suggesting that available funds may be directed to immediate consumption or alternative livelihood needs rather than environmental investments, with similar findings being reported by Diiro and Sam and Bosompem et al [48, 49].

Finally, awareness of legal frameworks also showed a negative association (IRR = 0.75, $p < 0.01$). This may reflect the lack of clear policy direction and delays in implementing Kenya's national *Prosopis juliflora* management strategy, which undermines household confidence to commit resources. This contrasts with Pham et al, who observed that clear and enforced regulations typically encourage greater adoption of sustainable practices [50].

4. Conclusions and Recommendations

This study examined the adoption patterns and determinants of *Prosopis juliflora* management interventions among households in Baringo South Sub-County, Kenya. The findings show that the wide range of adoption of *Prosopis juliflora* management interventions by households in Baringo South Sub-County reflects a practical response to the species' dual role as both an ecological threat and an economic resource. High participation in charcoal (84.85%) and firewood (47.73%) production demonstrates the importance of immediate livelihood needs and accessible market opportunities. Given this, policymakers and development partners should promote high-value and restoration-oriented practices such as livestock feed processing, land reclamation, and biochar production. Furthermore, support should target market development, labour-saving technologies, and technical backstopping to make these interventions more attractive and sustainable for rural households.

In terms of the determinants of adoption intensity, the study further revealed that resource endowment, institutional access, and livelihood orientation jointly influence household participation in *Prosopis juliflora* management, for instance, the positive influence of landholding size ($p < 0.01$) and market access ($p < 0.01$) highlights the enabling role of productive assets and localized demand for *Prosopis juliflora* products. On the other hand, negative associations with factors like credit access, information, and training indicate that institutional mechanisms have not yet translated into practical empowerment for resource-poor households. To address this imbalance, there is a need to strengthen extension services, improve access to affordable credit, and align training with practical field realities, all achievable through Farmer Field Schools (FFS), and collaboration among Kenya Forest Service (KFS) and Kenya Forestry Research Institute (KEFRI), and county extension officers. Moreover, introducing flexible financing models such as revolving funds or community savings groups will empower households and promote equitable participation.

Abbreviations

AIC	Akaike Information Criterion
ASAL	Arid and Semi-Arid Lands
BCIDP	Baringo County Integrated Development Plan
BIC	Bayesian Information Criterion
GPRM	Generalized Poisson Regression Model
IAPS	Invasive Alien Plant Species
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IRR	Incident Rate Ratios
KEFRI	Kenya Forest Research Institute
KES	Kenyan Shilling
KFS	Kenya Forest Service
KNBS	Kenya National Bureau of Statistics
NGO	Non-governmental Organization
ODK	Open Data Kit
PMF	Probability Mass Function
USD	United States Dollar

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Author Contributions

Loveness Gloria Phiri: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Visualization, Writing – original draft, Writing – review & editing

George Owuor: Conceptualization, Supervision, Validation

George Morara Ogendi: Conceptualization, Project administration, Supervision, Validation

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Loveness Gloria Phiri is a Master's student in the Collaborative Masters in Agricultural and Applied Economics (CMAAE) program, specializing in Environmental and Natural Resource Management at Egerton University, Kenya. She holds a Bachelor of Science degree in Agricultural and Applied Economics obtained at LUANAR in Malawi, and has experience in socio-economic research and rural development studies. Her current work evaluates the net economic benefits of *Prosopis juliflora* management in Baringo South Sub-County, Kenya, providing evidence to inform the designing of invasive species management strategies that improve household livelihoods while ensuring sustainable environmental management.

George Owuor is a professor at Egerton University, Agriculture Economics and Agribusiness Management Department. He completed his PhD in Agribusiness Management through DAAD-German Academic Exchange programme from Kiel University in Germany and Egerton University, Kenya in 2008, and his MSc. in Agricultural Economics at Egerton University-Kenya in 2002. Prof. Owuor currently serves as the Director of Research and Extension, and as Center Leader of the World Bank-funded African Center of Excellence in Sustainable Agriculture and Agribusiness Management (CESAAM) at Egerton University. Before the current position, Owuor served as Director of Income-Generating Units at Egerton University. He was also the Managing Director of Egerton University Investment Company from 2017 to 2021. Beyond his administrative roles, Prof. Owuor has played a pivotal role in postgraduate supervision, having successfully guided PhD and Masters students. His contributions to academia are further highlighted by his authorship of over 70 publications in national and international journals.

George Morara Ogendi is a professor at Egerton University, Environmental Science Department. He completed his Postdoc in Environmental Geochemistry & Toxicology at Arkansas State University – USA in 2008, a Ph.D. Environmental Geochemistry & Toxicology at the same institution in 2006, an M.Sc. Environmental Science at UNESCO-IHE, Delft, Netherlands in 1999, and a PGD in Limnology & Wetland Ecosystems at the Austrian academy of Sciences, Austria in 1998. Prof. Ogendi currently serves as the Acting Principal of Egerton University Nakuru City Campus, and prior to that, he served as the Board of Post graduate studies at Egerton University, Njoro campus from 2022 to 2025, and Director of the Dryland Research Training and Ecotourism Centre (DREC), Egerton University, Chemeron campus from 2017 to 2022.

Research Field

Loveness Gloria Phiri: Agricultural and Applied Economics, Environmental and Natural Resource Economics, Invasive Species Management, Environmental Valuation, Sustainable Resource Management.

George Owuor: Value Chain Development, Impact Assessment, Rural Agricultural Finance, Enterprise Development, Land Use Management.

George Morara Ogendi: Water Quality, Water Access, Water and Sanitation, Environmental Health, Climate Change Impacts, Mitigation and Adaptation, Natural Resource Ecology, and Biodiversity Conservation.