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DETERMINANTS OF GAZETTED FOREST DEPENDENCE AMONG FOREST-ADJACENT SMALLHOLDER FARMERS IN KENYA: CASE OF ELGEYO MARAKWET COUNTY

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ABSTRACT: *Forest resources play a crucial role in sustaining the livelihood of the global population. However, degradation of this vital and fragile ecosystem has been observed. This paper examined the determinants of forest dependence among forest-adjacent smallholder farming communities. Cross-sectional data from 419 households from randomly selected smallholder farming households living adjacent to the gazetted forest in Elgeyo Marakwet County, Kenya, was analyzed. We used a fractional Probit regression model to analyze these determinants of forest dependence. Socioeconomic and institutional factors, plot-level characteristics, cultural norms, and beliefs were hypothesized to influence forest dependence. Findings revealed that gender, government support, and membership in forest conservation groups were important factors influencing forest dependence. Further, flat land and fertile main agricultural land reduced forest dependence. Finally, under cultural norms and beliefs, farmers' perceptions of the forest as environmental beauty and scenery and as a source of traditional medicine and herbs increased forest dependence. We recommend policy and program intervention to promote gender participation and encourage government support and local community associations towards promoting gender participation and encouraging government support and local community associations. In addition, advocating for proper land reform policies to boost land productivity and adequate regulations for cultural activities should be encouraged to ensure the forest resource's sustainability and to promote farmers' livelihoods.*

KEYWORDS: Fractional Probit model, Gazetted forest, Forest dependence, Forest-adjacent smallholder farmers.

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INTRODUCTION

The wooded forests that sustain smallholder farmers around the world are vital to their livelihoods, as they not only impact agricultural output but also provide them with fuel, lumber, and non-timber forest products (Doimo *et al*., 2020). Forest degradation and tropical deforestation are two of the most significant threats to biodiversity worldwide. Human activities linked to land use practices, climate change, and human development pose a threat to this symbiotic relationship (Call *et al.*, 2017). Accordingly, the needs of sustainable forest management and smallholder farmers for biodiversity preservation, climate resilience, and global food security must be balanced (Nyelele & Kroll, 2020). This demonstrates how the difficulties these farmers have are intricately linked to the condition of the world's forests. Since trees are vital to their survival, smallholder farmers in Africa form a close bond with them. Unfortunately, the rapid deforestation brought on by resource exploitation and agricultural expansion is endangering their traditional way of life (Ajanaku & Collins, 2021). A call to protect these forests is crucial for communities because it will preserve their cultural legacy and ensure resilient, sustainable farming methods for sustainability. Smallholder farmers in Africa, who are often disenfranchised, support and profit from these ecosystems while maintaining a precarious balance (Duriaux *et al*., 2018).

In sub-Saharan Africa, smallholder farmers have a close bond with the trees that will shape their future. According to Abu and Arfin (2020), these farmers, who mostly practice subsistence farming, rely on forests to supply them with essentials like building materials, fuel wood, wild edibles, medicinal plants, and other forest products. However, this delicate balance is disturbed by long-term issues including population increase, irresponsible logging, and changes brought on by climate change (Nitoslawski *et al.*, 2021). Smallholder farmers face the pressing need for coordinated conservation efforts and sustainable practices as agricultural expansion encroaches on wooded areas. Smallholders who rely significantly on forest resources are disproportionately impacted by agricultural development into subtropical and tropical forests, which causes significant environmental harm (Levers *et al.,* 2021; Nerfa *et al.,* 2020). Furthermore, the vulnerability and dependence of rural agricultural communities in developing nations are increased by the shared property of forest resources; for this reason, local-level biodiversity conservation techniques are necessary (Adhikari et al., 2004). Smallholders in Sub-Saharan Africa value these woods because they protect watersheds, support biodiversity, and lessen the overall effects of climate change in the region. According to Ofoegbu *et al*. (2017), these National Adaptation Programs of Action (NAPAs) are largely acknowledged as national programs for forest-related conservation.

In Kenya, smallholder farmers play a crucial role in their community and rely on forests for their existence and means of subsistence, as they provide key resources for both economic gain and survival. The partnerships between community-led conservation initiatives and sustainable forest management programs are essential for Kenya's diverse and vital forest ecosystems, water availability, and the future survival of smallholder farmers (Mbeche *et al.*, 2021; Okumu & Muchapondwa, 2020). The lives of farmers are at risk, and environmental issues are getting worse due to deforestation caused by logging and agricultural expansion. A unique perspective on the dependence of smallholder farmers on the forest can be found in Elgeyo Marakwet County in Kenya's Rift Valley. Gazetted forest blocks are abundant in the county, and smallholder farmers who live nearby rely on them to support their livelihoods (Maua *et al.*, 2020). However, issues of forest degradation pose a threat to the fragile equilibrium in the area.

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The conservation and restoration of such degraded forest resources depend heavily on programs supporting alternative livelihoods, community involvement, and sustainable forest management (Rotich & Ojwang, 2021). This ensures the long-term health of the county's distinctive ecosystems, promotes biodiversity conservation, and supports the ongoing well-being of smallholder farmers.

The interaction between gazetted woods and smallholder farmers is a reflection of the delicate balance that exists between environmental conservation and livelihoods in the intricate web of interactions between humans and the environment (Grammatikopoulou & Vačkářová, 2021). Gazetted forests are vital for preserving biodiversity, mitigating the effects of climate change, and preserving ecosystems. Governmental organisations and other pertinent parties acknowledge and safeguard them. Their significance extends beyond environmental concerns to include the means of subsistence and livelihoods of smallholder farmers who depend on these forested areas to survive (Fungomeli *et al.*, 2020). Amongst gazetted woodlands and forest communities, there is a complex interaction between natural factors, cultural customs, and social factors. Furthermore, a sizable portion of household dwellings within five kilometres of the Kenyan forest reserves' edge make up forest communities (Wass, 1995). Both the local community and the broader natural landscape are affected by the numerous opportunities and challenges that come with such a partnership. Therefore, investigating the various facets of gazetted forest dependency among smallholder farmers in the periphery was essential.

Several studies have examined the nature of forest dependence among communities that are adjacent to forests (Angelsen *et al.*, 2011). However, there have been fewer considerations focusing on the factors that influence forest dependence and applying a fractional response model approach for analysis. A number of studies have focused on other methodologies for descriptive and inferential while using logistic regression models like Logit, Tobit, Probit and multivariate regression analysis to assess community forest dependency (Adam & El Tayeb, 2014; Adhikari et al., 2004; Papić Milojević & Bogdanov, 2024). Other studies applied the stochastic frontier model to estimate technical efficiency in agriculture and relate it to forest and agroforestry dependency. In these approaches, farm output was considered to estimate efficiencies while relating them to drivers of forest and agroforestry dependence (Illukpitiya, 2006; Lindara *et al.*, 2006; Lwiza, 2013). Further, Talpă *et al. (2022)* focused on quantifying and measuring socioeconomic factors to evaluate forest dependence. In contrast, Menze *et al.* (2009) highlighted the limitation of regularized regression methods and suggested random forest classifier measurements with its associated Gini feature in order to enhance the measurement of variables closely related to fractional response, which this study addressed. Our study specifically bridged the gap by adopting a new approach of measuring, identifying forest dependence determinants, and applying fractional response to evaluate forest dependence among forest-adjacent communities.

This paper aims to assess and clarify the complex relationships and interdependence between gazetted forests and smallholder farmers, highlighting the intricate ways in which this ecosystem is vital to the livelihoods of smallholder farmers. We navigated through the socioeconomic, plot characteristics and cultural determinants that drive this dependency, intending to contribute to a deeper understanding of this critical dynamic through empirical evidence and examination of relevant literature. We emphasized the need for holistic approaches to forest management that consider ecological preservation and the welfare of those who depend on these vital landscapes. It was essential to recognize that the implications of

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gazetted forest dependence among smallholder farmers extend far beyond the immediate communities involved. Therefore, this intricate interdependence calls for a comprehensive and nuanced approach that reconciles the imperatives of environmental conservation with the aspirations of those whose lives are intricately woven into the fabric of gazetted forests.

METHODOLOGY

The study area

The study was carried out in Elgeyo Marakwet County, Kenya (Figure 1). Elgeyo Marakwet County is located in the North Rift region of Kenya. It covers a total area of 3,029.6 km^2, constituting 0.4 percent of Kenya’s total area. It extends from latitude 0º 20′ to 1º 30′ to the North and longitude 35º 0′ to 35º 45′ to the East. Bordering West Pokot County to the North, Baringo County to the East, Uasin-Gishu County to the Southwest and Trans Nzioa to the Northwest (County Elgeyo Marakwet, 2017). The County's wide altitude variation results in three distinct agro-ecological zones: the lowland, transition, and highland zones (GoK, 2013). The lowland zone forms part of the base of Kerio Valley, with an altitude between 1,200 and 1,500 meters above sea level. The transition zone altitude range is between 1,500 meters and 2,000 meters above sea level and constitutes part of the Kerio Valley escapement. The highland zone has an altitude range of 2,000 meters to 3,150 m above sea level and is a part of the Kenyan highlands. The county experiences a bimodal rainfall pattern ranging from 700 mm to 1,700 mm annually. The first onset of rain occurs in March/April and the second increases in October/November. The annual mean temperatures in the highlands range from 18ºC – 22 ºC while the lowlands range from 25ºc – 28ºc (County Elgeyo Marakwet, 2020). These agro ecological variations contribute to the county's microclimatic diversity, which is critical for influencing its ecosystems, agriculture, and people's means of subsistence. Understanding these climatic aspects is crucial for the county's efforts in forest resource management and sustainable land use planning.

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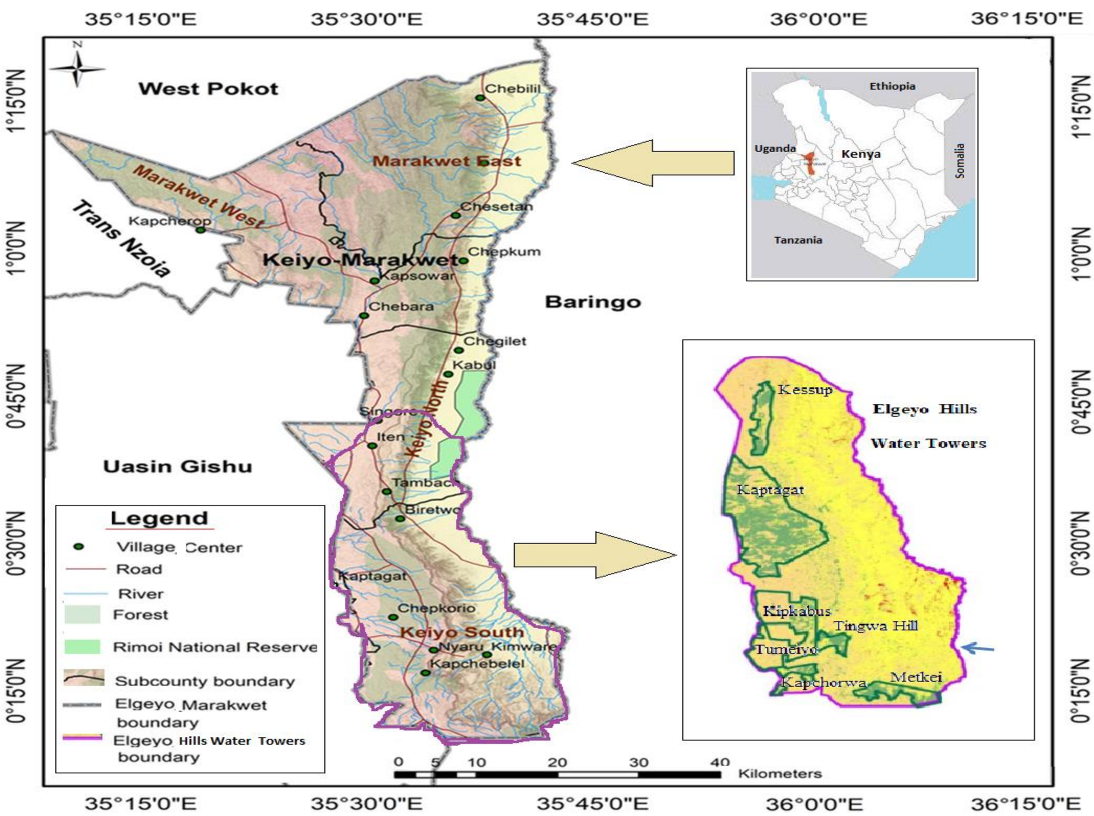

Figure 1: Study area map

Source: *Modified from KWTA report, (2020)*

The study area was chosen because the county is endowed with gazetted forest resources harboring the Elgeyo Hills Water Towers, located in the highland regions of the county and is essential to smallholder farmers who depend on it for their livelihoods. Due to the mutual interaction between the forest resources and smallholder livelihoods in the county, the gazetted forest degradation has been evidenced in the study area. This necessitates a sustainable management approach to maintain the county's environmental integrity and ensure smallholder farmers' prosperity. The study aimed to understand the determinants of forest dependence in the dynamics of striking a balance between conservation and local community requirements. Elgeyo Hills Water Towers is one of the leading water towers in Kenya, located along the edges of the Great Rift Valley, covering an area of 108,194 Ha. The water towers embody seven gazetted forest blocks, namely Kaptagat, Kipkabus, Kessup, Kapchorua, Tingwa Hills, Tumeiyo and Metkei, covering 23.4% (25,354 Ha) of the total Water Tower area (Kenya Water Towers Agency, 2020).

Sampling procedure and sample size determination

The sample size required for the study was determined to be proportionate to the number of households in the sampling methodology proposed by Yamane (1967) in Equation 1.

$$n = \frac{N}{1 + N(e)^2} \qquad (1)$$

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where n = Sample size, N = population size, and e = precision level (α = 0.05). Since the proportion of the population is known, N = 39,180 and the value of e = 0.05. The sample size obtained is 396.0377, approximated as 396. The anticipated problem of non-response is expected to be at a lower rate due to non-self-administered questionnaires estimated at 5% of the sample size. The approximate number of sampled households was estimated at 419 to cater to non-responsive respondents (Table 1). A random approach was used to select households who are the smallholder farmers identified as forest-adjacent communities. These forest communities are groups of persons who have a traditional association with a forest for the purposes of livelihood, culture or religious purposes (RoK, 2016).

Table 1: Sample size determination and computation for forest dependence

Clusters (forest degradation)	Gazetted forest block	Population	Sample selected
High degradation cluster **(30%)**	Kipkabus forest block	8,229	88
	Kaptagat forest block	18,515	198
	Kessup forest block	4,114	44
Medium *(69%)* and Low *(1%)* degradation clusters **(70%)**	Tumeiyo forest block	4,208	45
	Tingwa Hills forest block	1,496	17
	Kapchorwa forest block	1,496	15
	Metkei forest block	1,122	12
Totals		**39,180**	**419**

The training of the data collection enumerators took place in November 2023. A pilot study was carried out at Cheptong'ei Forest Station, which forms part of the Cherang'ani water towers in Marakwet West Sub-county in November, 2023 to guarantee data quality, dependability, and the robustness of the data collection tool. Thereafter, the primary data collection period was conducted in December, 2023. The data were collected with the aid of the Kobo Collect tool box application for data collection. The Egerton University Institutional Scientific and Ethics Review Committee (EUISERC) granted ethical approval for the study under approval number EUISERC/APP/314/2024, and the National Commission for Science, Technology, and Innovation (NACOSTI) issued a research permit under license number NACOSTI/P/23/30806. Since there was no documented list of the forest-adjacent community members, household heads were interviewed through random walks, in which each forest block cluster's starting point was determined by the enumerator inside the study area. Following the identification of the patterns and directions from each location, a random selection of households was used to pick the sampled respondents.

Measuring forest dependence

Forest Dependence (FD) was measured as a proportion of the Forest Income (FI) to the Total Household Income (HHI) (FD = FI/HHI). FD is an economic measure affected by commodity market prices and forest product prices, affecting total income whose value ranges between 0 and 1, hence a fractional response. HHI was obtained as a summation of FI, Agricultural Income (AI), Off-farm Income (OFI) and Return to Wealth Income (RWI) (Ali *et al.*, 2020; Amadu *et al.*, 2021; Chhetri *et al.*, 2016).

FI was presented as all possible annual quantifiable income in Kenya shillings (Kshs) derived from the gazetted forest. They include income from firewood, fodder and Non-Wood Forest

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Products (NWFPs) sources. It was obtained as a total value of all annual income obtained from firewood extracted; fodder collection; cattle, sheep, goats and donkeys grazing; honey collected; poles/fencing/building materials collected; traditional medicines/herbs/fruits extracted; forest crops income from Plantation Establishment and Livelihood Systems (PELIS)/*(Shamba System)*; forest nursery activities income; Mushrooms, thatching grass; hat smearing mud extracted; and forest income earned from labour offered for forest-related activities like tree nursery activities, tree planting activities, tree nurturing activities, training attendance and transport allowances.

AI was calculated as the total annual value in Kenyan shillings (Kshs) of the household's on-farm crops (maize, beans, potatoes, and vegetables, mainly kales/*(Sukumawiki)* cabbages and black nightshade/*(Managu)* and passion fruits) and livestock enterprise products (milk, poultry, meat, eggs, and sheep wool) and livestock sale value (cattle, sheep, goats and chicken). OFI was calculated as the annual value of off-farm income from business activities, informal off-farm employment, formal off-farm employment, and transfer payments such as gifts and tokens. Household RWI was calculated as a percentage of an estimated annual net worth value estimated at 10% of annual household net worth. For the subsistence case, the annual value was measured as an opportunity cost of a parameter being measured. The FD value is presented in Equation 2.

$$FD = \frac{FI}{HHI} \quad (2)$$

where FD is the dependent variable, a fractional response such that $0 \leq FD \leq 1$; FI is the total annual forest income from both Wood and Non-Wood Forest Products (NWFP). HHI is the annual total household income (FI + AI + OFI + RWI).

Analytical technique

The study aimed to assess the determinants of forest dependence among forest-adjacent smallholder farmers in Elgeyo hills water towers located within Elgeyo Marakwet County, Kenya. To assess this, both the dependent and independent variables were identified and estimated. A fractional regression model was then used to assess the determinants of forest dependence. The model enabled the prediction of values for the fractional dependent variable and the marginal effects of the independent variables. A fractional model is suitable for fractional response interpretations; thus, its applications are ideal in assessing Gini coefficient/income inequalities, pollution and poverty rates (Essel-Gaisey & Chiang, 2022; Shabnum & Malik, 2023; Wulff, 2019). The model developed presents simple quasi-likelihood estimation methods for regression models with a fractional dependent variable (Papke & Wooldridge, 1996). There are two common options for the analysis using a fractional response model, which are beta regression *(betareg)* and fractional regression *(fracreg)*. Beta regression is only possible when the fractional response does not include a 0 or 1 value, whereas the fractional regression includes either of the extreme values (0 or 1) (Dorta, 2016; Ogunleye, 2018; Rodriguez *et al*., 2018).

The survey data indicated that some households had no forest dependence; the fractional Probit regression model was chosen for analysis. Fractional response models are considered flexible as compared to the standard polynomial functions, which are sufficient for the metadata as they

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produce the minimum deviance and maximum log likelihood values (Sohail *et al.*, 2019). Given that the dependent variable y denotes the fractional response variable and x the set of independent variables with β parameter vectors. Then, the generalized model is specified in Equation 3.

$$\mathrm{E}[y \mid x] = G(x'\beta) \tag{3}$$

where G(•) denotes a bounded function ($0 \leq y \leq 1$), typically a cumulative distribution function like the logistic fractional logit model or the normal fractional Probit model (Sohail *et al.*, 2019). The choice between fractional logit and fractional Probit regression models was guided by the underlying distribution of the data set. Logistic distribution, using the fractional Logit model could yield an appropriate estimated outcome for interpreting odds ratios. However, the Probit model could be computationally more intensive to estimate because it involves the inverse cumulative distribution function of the normal distribution that provides a better evaluation of more robust estimations (Greene, 2014). Considering the functional form of Forest Dependence (FD) as a dependent variable and X_i as independent variables are identified as the determinants of gazetted forest dependence, it was presented as $\mathrm{FD} = \mathrm{f}(\mathrm{x}_I)$, The general form of the fractional Probit regression model was specified in Equation 4.

$$\mathrm{E}[\mathrm{FD} \mid \mathrm{x}_i] = f(\mathrm{x}'\beta) = \varphi^{-1}(\mathrm{FD}_i) = \beta_0 + \beta_{1i}\mathrm{x}_{1i} + \beta_{2i}\mathrm{x}_{2i} + \ldots + \beta_{ki}\mathrm{x}_{ki} + \varepsilon_i \tag{4}$$

where FD_i denotes the forest dependence rate as a dependent variable and X_i as a list of demographic factors, social capital networks, farm-land characteristics and cultural norms and beliefs as independent variables for i^{th} observations (i= *1,2,3,…, n),* Φ^{-1} is the Probit link function indicating an inverse of the cumulative distribution function (CDF) of the standard normal distribution, and ϵ_i is the disturbance error. The marginal effect of x_{1i} on FD_i was computed in Equation 3.5. as a derivative of the expected value with respect to x_{1i} for a fractional Probit model.

$\mathrm{E}(\mathrm{FD} \mid \mathrm{x}_{1i}, x_{ki}) = \Phi^{-1}(\beta_0 + \beta_{1i}\mathrm{x}_{1i} + \beta_{ki}\mathrm{x}_{ki})$, derived as,

$$\frac{\partial \mathrm{E}(\mathrm{FD}_i \mid x_{1i}, x_{ki})}{\partial x_{1i}} = \beta_{ki}.\Phi^{-1}(\beta_0 + \beta_1 x_{1i} + \ldots + \beta_k x_{ki}) \tag{3.5}$$

where, $\frac{\partial \mathrm{E}(\mathrm{FD}_i \mid x_{1i}, x_{ki})}{\partial x_{1i}}$ denote changes in x_{1i} affect the expected value of the dependent variable FD_i, β_{1i} is the coefficient for x_{1i} indicating the direction and strength of the relationship between x_{1i} and FD_i. The expression $\Phi^{-1}(\beta_0 + \beta_{1i}\mathrm{x}_{1i} + \beta_{ki}\mathrm{x}_{ki})$ is the term that scales the coefficient by the value of the standard normal probability distribution function $(\beta_0 + \beta_1 x_{1i} + \ldots + \beta_k x_{ki})$ (Henriques, 2010; Wooldridge, 2010). The list of variables used is presented in Table 2.

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Table 2: Definition of the variable for forest dependence used in the study

Variables	**Definition and measurement**
Forest Dependence (FD)	FD = Forest Income *(FI)* / Total Household Income *(HHI).*
Demographic characteristics	
Age	Age of the household head *(Number of years)*
Sex	Sex of the household respondent (*1=Male,0=Female)*
Household size	Number of the household members *(Number of members)*
Education level	Years of formal education *(Years)*
Land size	Household's main land size *(Hectares)*
Social and capital networks	
Forest access distance	Household's proximity to the nearest gazetted forest *(Walking minutes)*
Financial access distance	Household's proximity to the nearest financial institution *(Walking minutes)*
Market access distance	Household's proximity to the nearest market *(Walking minutes)*
Credit access	Household head access to credit facility *(Index)*
Road condition	Nature of road condition *(Index)*
Information access	Household head information access on forest conservation *(Index)*
Training and extension access	Household head conservation training and extension access *(1=Yes, 0=No))*
Forest group membership	Household head membership in a forest conservation group *(1=Yes, 0=No)*
On-farm trees	Presence of on-farm trees in the main household land *(1=Yes, 0=No)*
Government support	Government support on on-farm tree establishment *(1=Yes, 0=No)*
Perception of plot-level characteristics	
Soil fertility perception	Household's perception of mainland soil fertility *(1=Poor, 2=Moderate, 3=Good fertile soil)*
Land slope perception	Household's perception of mainland slope *(1=Gentle, 2=Moderate, 3=Steep slope)*
Soil structure perception	Household's perception of mainland soil structure *(1=Shallow, 2=Moderate, 3=Deep soil).*
Cultural norms and beliefs	
Cultural heritage and ceremonial site	Household's forest perception as cultural heritage and ceremonial site *(1=Yes, 0=No)*
Environmental beauty and scenic sites	Household's forest perception as environmental beauty and scenery *(1=Yes, 0=No)*
Traditional medicine and herbs source	Household's forest perception as traditional medicine & herbs source *(1=Yes, 0=No)*

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RESULTS AND DISCUSSION

Descriptive statistics for forest dependence variables

Table 3 presents the descriptive statistics of the demographic characteristics, social and capital networks, main plot-level characteristics and cultural norms and belief variables used.

Table 3: Descriptive statistics for forest dependence variables

Variables	Mean	Standard Deviation
Demographic characteristics		
Age	46.94	10.99
Sex	0.56	0.50
Household size	5.41	1.91
Education level	2.73	0.69
Land size	1.43	0.82
Social and capital networks		
Forest access distance	26.76	20.13
Financial access distance	52.17	32.34
Market access distance	32.25	30.95
Credit access	0.62	0.16
Road condition	0.49	0.47
Information access	0.59	0.51
Training and extension access	0.45	0.41
Forest group membership	0.39	0.35
On-farm trees	0.89	0.85
Government support	0.47	0.42
Plot-level characteristics		
Soil fertility perception	1.94	1.91
Land slope perception	1.85	1.81
Soil structure perception	1.99	1.97
Cultural norms and beliefs		
Cultural heritage and ceremonial site	0.97	0.95
Environmental beauty and scenic sites	0.96	0.95
Traditional medicine & herbs source	0.98	0.96

The household's average age was 46.94 years, suggesting that the sample was mature members of the community. The average size of households was 5.41, revealing that the average size of members of the household can be approximately 5 members. Using the scale (primary = 1, secondary = 2, tertiary = 3), the mean score was 2.73, indicating a moderately high level of education. The average main household land size was 1.43 hectares. A sex code of 0.56 indicates that there were slightly more male participants than female participants, and the males accounted for 55.61%, whereas females constituted 44.39% of the sample, indicating that the sample was fairly balanced in terms of gender.

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Regarding forest frontier accessibility, it took an average of 26.76 walking minutes to get to the boundary of the closest gazetted forest, 32.25 walking minutes to get to the closest market, and 52.17 walking minutes to get to the closest financial institution. Credit had a mean response of 0.62, and information services 0.59, revealing that credit and information access were moderately accessible to the respondents. Government assistance on on-farm tree establishment means a rating response of 0.47, and training and extension services 0.45, indicating that they were comparatively scarce. The average perception of infrastructure quality was reflected in the road condition mean of 0.49. On-farm tree planting was more prevalent, with a mean score of 0.89, but fewer respondents reported membership in groups related to forest activities (0.39).

The households self-assessed plot conditions by providing their rated perceptions on main plot characteristics. The average score was 1.94 for the perception of soil fertility, 1.85 for the perception of land slope, and 1.99 for the perception of soil structure. These findings show a moderate degree of variation in farmers' assessments of the quality of their land, which could have an impact on forest conservation and land use practices. Households' cultural values regarding land use were clearly visible. The presence of ceremonial sites and cultural heritage received an average score of 0.97, while scenic sites and environmental beauty received an equal score of 0.96. With a mean score of 0.98, the importance of farms and forests as sources of herbal remedies and traditional medicine was also highlighted. These findings demonstrate the strong cultural ties that communities have with their land and natural resources.

Descriptive statistics for the dependent variable (FD)

The assessment of the forest dependence (FD) variable, derived as a ratio of forest income to the total household income, had an average rate of 0.266 and a range that lies between 0, representing absolutely no forest dependence and 0.998 indicating the highest level of forest dependence. (SD = 0.234, range = 0 to 0.998). Figure 2 represents the distribution of the forest dependence variable.

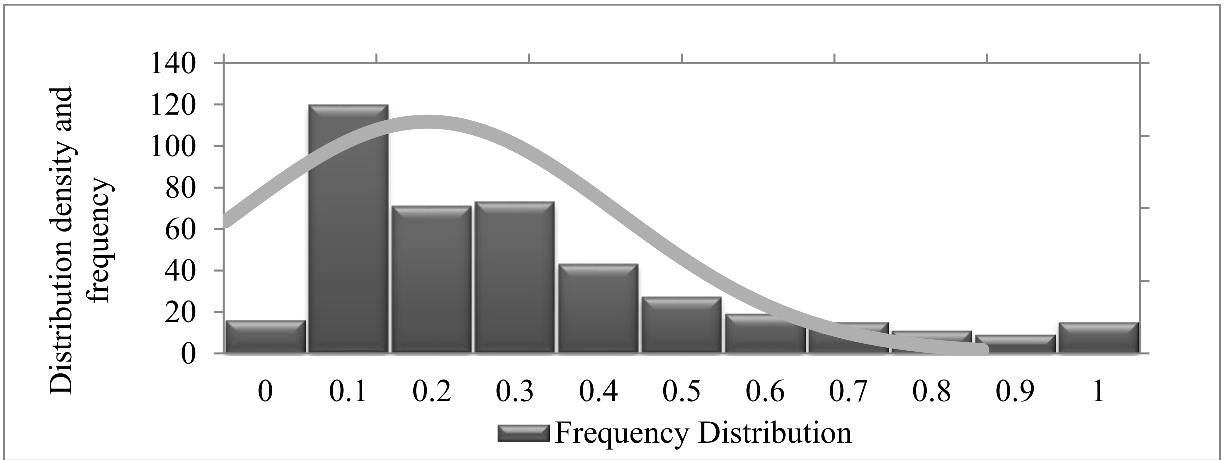

Figure 2: Forest dependence normal distribution density graph

The figure's histogram displays a positively skewed distribution, with most values clustering between 0.1 and 0.4 and a sharp drop in frequency as values get closer to 1.0. The dataset appears to be right-skewed and not normally distributed, as indicated by the highest frequency

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occurring in the 0.1–0.2 category. According to this pattern, fewer respondents fell under the higher values, while the majority of responses were concentrated at lower values. The skewness of the data is visually reinforced by the addition of a smooth density curve overlay.

Based on the annual average total household income, agricultural activities were found to be the main source of income, accounting for around KShs. 114,722.83. followed by return-to-wealth income (KShs 86,587.95), off-farm income (KShs 64,407.64), and forest income (KShs 71,689.27) come next; hence, the total annual average household income of KShs 337,407.69 was obtained. The mean of the forest dependence ratio was obtained as 0.266, meaning that on average, 26.6% of the household income comes from forest resources. Given this degree of reliance, it is noted that forest products contributed significantly to rural household economies, enhancing both non-agricultural and agricultural revenue streams. These findings confirm that forests played a significant role in livelihoods. They also support findings from other contexts where environmental income supports livelihood diversification and rural resilience (Sadeghi *et al.*, 2023; Siltanu *et al.*, 2022).

Econometric analysis results

The econometric analysis results and discussion are presented in Table 4.

Table 4: Average marginal effects for the fractional Probit regression model

	dy/ex	Standard errors	P>z
Demographic Characteristics			
Age	0.016	0.053	0.770
Sex	**-0.020**	0.011	**0.074***
Household size	-0.023	0.040	0.565
Education level	-0.003	0.044	0.940
Land size	-0.010	0.019	0.602
Social and capital networks			
Forest access distance	**-0.045**	0.012	**0.000***
Financial access distance	0.010	0.018	0.590
Market access distance	0.011	0.013	0.370
Credit access	-0.064	0.041	0.119
Road condition	-0.016	0.022	0.454
Information access	-0.008	0.039	0.845
Training and extension access	0.045	0.040	0.252
Forest group membership	**-0.030**	0.008	**0.000***
on-farm trees	-0.006	0.030	0.848
Government support	**-0.033**	0.008	**0.000***
Plot-level characteristics			
Soil fertility perception	**-0.133**	0.071	**0.060***
Land slope perception	**-0.181**	0.048	**0.000***
Soil structure perception	-0.007	0.113	0.949
Cultural norms and beliefs perceptions			
Cultural heritage and ceremonial site	0.010	0.049	0.840
Environmental beauty and scenery	**0.128**	0.054	**0.017****
Traditional medicine & herbs source	**0.139**	0.049	**0.005***

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Note: (*** = significant at 10%, ** = significant at 5%, * = significant at 1% significance levels)

The average marginal effect results were obtained by first estimating the fractional Probit regression model and thereafter the marginal effects were obtained. Since the parameter estimates in the model can only show the response of the independent variable on the dependent variable and not the magnitude change (Dorta, 2016), a further derivation of the average marginal effects of the predictor variable was estimated, and significant predictors of forest dependence levels were identified. The Wald chi-square test in the fractional Probit regression analysis found a statistically significant relationship between the independent and dependent variables. The model test ($\chi^2(21) = 137.58$, $p < 0.001$) implies a significant difference from zero in at least one of the independent variable coefficients. The model's log pseudolikelihood of -232.55328 demonstrated how well the model fit the data. With a pseudo-R-squared of 0.0423, the model was able to explain 4.2% of the variation in the dependent variable. Even though this indicates a modest fit, the model might still be instructive for predictors that are statistically and practically significant. The statistical results demonstrate the model's potential usefulness in understanding the elements that impact the outcome under consideration, indicating that the collection of independent variables included in the analysis significantly contributes to explaining variation in the dependent variable.

Sex variable was found to be significant at the 10% significance level. The sex of the household head negatively influences forest dependence. This could be attributed to males exhibiting higher levels of education and more access to and control of productive resources, making them less likely to depend on forest-based resources. Despite the findings that 46.54% of the households reported at least obtaining a secondary level of education, male-headed households were predominant in this study, accounting for 56.61% as compared to females at 44.39%. This is consistent with the findings that gender aspects influence perceptions of effectiveness on community adaptation and dependence on natural resources (Assan *et al*., 2018). This observation is supported by the finding that household characteristics such as uneducated heads significantly influenced the use of forest resources more than male heads (Mukete *et al*., 2018), indicating some degree of variance between male and uneducated heads, who could as well be female. Contrary to men's predominance in economic activities, females also engage in mutual social network interactions of agricultural and non-agricultural activities and benefit from such interventions (Bourne *et al*., 2015; Perez *et al*., 2015). Whereas men and women depend on forest resources for their livelihoods, both genders are impacted by natural resource endowments and elements such as climate change and environmental impacts. However, women bear the highest burden as a result of their vulnerability and dependence on natural resources (Djoudi & Brockhaus, 2011; Nyangute, 2019).

An assessment of the household distance to the nearest forest revealed that an increase in the distance to the nearest forest in walking minutes resulted in a negative significant effect at the 1% significance level. This revealed that greater proximity to the forest is linked to decreased forest dependence. This can be explained by the observation that those members closer to the forest tend to have greater tendencies of accessing the forest-based resources with ease; hence, members of the community close to the gazetted forest tend to depend more on it than those far away. These findings concur with that of Tibesigwa *et al.* (2019), who observed that their estimated results revealed distinct and robust contributions by natural habitats of wild pollinator forests to on-farm-level crop revenue, where habitats near plots contribute much

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more value to inhabitants than those farther away. In another study, proximity to roads and the nearest town was found to have a detrimental effect on riparian forest amount and quality (Zimbres *et al.*, 2018), and this could exacerbate the negative effect of forest dependence.

Membership in a forest conservation-related group revealed a negative significant impact on forest dependence by smallholder farmers' forest dependence at 1%. The smallholder membership in a forest conservation group yielded a significant negative effect. The membership in a forest group could lead to community forest associations with formal structures that promoted a community participatory approach to forest conservation and management. It also provided a clear linkage between forest and community, with democratically elected leadership and well-organized group resources. Such groups engaged in economic activities like forest tree nurseries and other forest access groups and user rights. Therefore, community-based natural resource management has become integral to formulating relevant community and management authorities and partnership policies (Gatiso, 2019). Moreover, the prime goal of Participatory Forest Management (PFM) initiatives is to focus on local communities as key stakeholders in sustainability (Gashu & Aminu, 2019). A study by Dessie *et al.* (2019) affirmed that the two types of associations, informal and formal, were identified as high and attributed to smallholder farmers participating in tree production systems. This reaffirms the significance and contribution of forest farmer groups in conservation and restoration strategies

The household perceptions were interrogated as to whether they agreed or not that the government supported them in establishing on-farm forests. The assumption here was that by establishing a farm woodlot, they would reduce pressure on forest dependence. The results showed a significant negative effect at the 1% significance level. This finding underscores the importance of government support for programs that contribute to on-farm solutions for timber and non-timber products, which will ultimately reduce the over-reliance of the nearby forest to provide them. For this reason, smallholder farmers who depend heavily on forest resources are especially affected because they are usually impoverished and lack institutional support that can be properly implemented through the governmental agencies. The strength and role of local resource governance institutions play a crucial role in the dependency and demand for timber and Non-timber Forest Products (NTFPs) (Steele *et al.*, 2015). Although Forest dependency is mainly subsistence-oriented for meeting basic household requirements (Chakraborty *et al.*, 2018), the governing and management authority has a critical role in ensuring the sustainable utilization of the gazetted forest resource. While advocating for strategic government support, one needs to be cognizant of the limitations observed by Rahayu *et al.* (2024) that local government support for the implementation of forest conservation activities may still be limited and basically concentrated within a few stakeholders.

The results of plot-level characteristics indicated that farmers' perceptions of soil fertility significantly impacted their forest dependence. A higher farmer's perception of soil fertility of the main household land yielded a significant negative at the 10% significance level. This can be attributed to the observation that soil fertility increases generally increase farm productivity and hence increase rewards and benefits from farm-based economic activities. This could in turn increase the household well-being, thereby making them less likely to depend on forest-based resources. Since agricultural land use is significantly associated with deforestation (Kazungu *et al.*, 2021), land soil fertility plays a key role in forest conservation and restoration strategies. Kuria *et al.* (2019) supported this sentiment, using empirical evidence to explore the

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extent to which farmers' indicators of soil quality vary with land degradation status, noting that there were variations in the farming practices by considering soil fertility and land degradation status. Smallholder farmers will realize increased productivity in their on-farm activities, alleviating their forest dependence.

The household perception of the steeper slope of the land indicated a significant negative average effect at the 1% significance level. This can be demonstrated by the spatial variations in soil properties that are influenced by slope. It was observed that steeper sloped land generally was not productive for agricultural activities, and farmers often devote such pieces of land for trees and woodlots. Therefore, the presence of more on-farm trees could be attributed to some degree of reduced forest dependence. This is supported by another study, which revealed that land slope and quality of land were demonstrated to have an impact on perceptions, spatial variability and decision-making on agricultural activities (Martey & Kuwornu, 2021; Mulu *et al.*, 2022; Soropa *et al.*, 2021). Furthermore, Agbeshie and Abugre (2021) studied the rehabilitated degraded land to determine the influence of slope on soil fertility attributes and often devoted the growth performance of trees, acting as a substitute for forest product extract, especially firewood extraction for domestic energy sources. They revealed that the mid-slope position, as part of three slope categories, namely up-slope, mid-slope and downslope, recorded the highest tree growth characteristics. Hence, tree productivity is consistent with this study's findings that an increase in leading household soil fertility and land slope can be attributed to decreased forest dependence. Such interactions can be further enhanced through integrated and multifaceted soil and land management strategies in checking environmental degradation (Bazie *et al.*, 2020; Miheretu & Yimer, 2018).

The findings revealed that forest dependence increased as the farmer's perception of the forest as an environmental beauty and scenery site increased at a 5% significance level. The surrounding community frequently visits the forest in the study area to enjoy its scenic and serene environment. Some sites visited include forest reserves within the Great Rift Valley escarpments, offering an ambient environment for relaxation and enjoying the serene environment. The forested areas becomes susceptible to exposure, more exploitation of forest-related resources, and increased dependence.The history of indigenous and local communities traditional knowledge-based ways of managing their forests and agricultural landscapes provides insights into concepts and strategies that could be useful for adjusting to environmental conservation and mitigation strategies (Parrotta & Agnoletti, 2012).

Forest dependence increased with an increase in the perceptions of the forest as a source of traditional medicine and herbs at a 1% significance level. Local communities heavily depend on forests as a primary source of traditional medicine and herbs. These forests harbor a rich diversity of plant species known for their medicinal properties, which are integral to indigenous communities' cultural and healthcare practices. The reliance on forest resources for traditional medicine underscores the interconnectedness between community well-being and forest conservation efforts. It could have led to an increase in frequency of accessing forested areas for the purpose of extracting traditional medicine and herbs, thereby increasing forest dependence among the residents in the study area. However, sustainable management practices are essential to preserve these medicinal plants for future generations amidst growing pressures on forest ecosystems. Notably, forest use is significantly influenced by human culture (Cuni-Sanchez *et al.*, 2019), as well as their societal norms and beliefs. Mulungo *et al. (2020)* acknowledged that many cultural practices were involved in managing forests and tree systems,

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such as ceremonies, trenching, bark slashing, ring barking, spot weeding, and the use of organic manure and pesticides; food and medicinal species were also regarded as important. Different ethnic groups have different behavioral norms governing the adoption of forest-related aspects. In agroforestry, for instance, farmers' personal social and cultural preferences affect their goals and adoption choices (Nguyen *et al.*, 2021). Additionally, norms and customs that shaped the harvesting of wood-based and vegetal-based NTFPs were noted that shaped the harvesting of wood-based and vegetal-based NTFPs (Kimengsi & Mukong, 2023).

CONCLUSION AND POLICY IMPLICATION

The findings of this study provide valuable insights into the multifaceted determinants of forest dependence within the local community context, particularly focusing on demographic characteristics, social and capital networks, perceptions of on-farm land characteristics, and cultural norms and beliefs. Gender emerged as a significant factor influencing forest dependence, with women portraying more tendencies to depend on forests compared to men. Smallholder farmers' proximity to forest, membership in forest conservation groups and perceptions of government support on on-farm tree establishment were also significant in shaping forest dependence levels. Members of the community living near the forest are prone to depend more on the forest as compared to those residing far away. Likewise, being a member of a forest group and positive affirmation of government support are associated with lower rates of forest dependency. The household's perceptions of soil fertility and steeper land slopes were associated with decreased forest dependence as well. Finally, higher perceptions of forests as environmental beauty sites and sources of traditional medicine and herbs were significant determinants, leading to increased forest dependence. This highlights the intricate relationship between societal values and resource utilization practices. These findings underscore the complex interplay of socio-cultural, economic, and environmental factors in shaping forest dependence within local communities and emphasize the importance of adopting holistic and sustainable forest management strategies.

The policy implications arising from these insights include the importance of promoting gender-inclusive approaches in forest management initiatives to address disparities in forest dependence between males and females. Additionally, fostering community participation in forest conservation groups, particularly among members with proximity to the gazetted forest, and enhancing perceptions of government support can contribute to reducing forest dependence and promoting sustainable resource management practices. Efforts to improve land and soil management practices, such as enhancing soil fertility and focusing on perceptions of land slope issues, can further mitigate forest dependence by enhancing agricultural productivity and reducing pressure on forest resources. Promoting income diversification options concerning alternate livelihood sources, institutional reforms, and infrastructure facilities can also reduce forest dependency, giving room for sustainable forest management initiatives. Furthermore, recognizing and incorporating traditional knowledge and cultural values regarding forests into policy and management frameworks can foster more inclusive and effective conservation strategies. Ultimately, the findings emphasize the need for collaborative efforts involving governments, local communities, non-governmental organizations, and other stakeholders to develop and implement policies and programs that address the complex drivers of forest dependence while promoting sustainable forest management and conservation practices.

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Therefore, there is a need for integrated and holistic approaches to forest management that consider the socio-cultural, economic, and environmental dimensions of local communities' interactions with forests.

Compliance with ethical standards, ethical approval

The authors affirm that all procedures performed in studies involving human participants were by the ethical standards of the institutional and/or national research committee and as stipulated in the ethical code of standard requirements and that of the NACOSTI clearance permit.

Disclosure Statement

The authors hereby disclose that there are no financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

Conflict of interest

The authors declare that they have no competing interests.

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