Research Square

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Socioeconomic Drivers and Management Effectiveness Influencing Forest Degradation in Mudi Forest Reserve, Blantyre, Malawi

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Abstract

Forest degradation continues to threaten protected forests in Malawi despite existing conservation policies. Degradation of forest ecosystems in the Mudi Forest Reserve is further being exacerbated due to increasing dependence on forest resources and persistent governance challenges. This study assessed the impact of socioeconomic drivers and management effectiveness on forest degradation through household, institutional, and satellite-derived evidence. The socioeconomic factors and management efficiency affecting forest degradation were examined in this study from the household and institutional perspective, as well as using satellite-derived information. The study specifically aimed to assess socioeconomic activities leading to forest degradation in Mudi Forest Reserve; and; Determine the socio-economic consequences of forest degradation in Mudi Forest Reserve and evaluate the current forest management practices in the Mudi Forest Reserve and their effectiveness.

The study utilised mixed methods approach combined the use of household surveys, key informants, field observation and Normalized Difference Vegetation Index (NDVI) derived from Landsat imagery (2000–2024). Quantitative data were analysed using descriptive statistics, while qualitative responses were analysed thematically and integrated with long-term vegetation trends to explain patterns of forest degradation.

Key drivers include charcoal production, firewood, and agriculture. Specifically, 62.6% of the respondents reported getting firewood from the forest, 49.1% of the respondents reported cutting trees for income generation, 59.6% of them for land clearance for crop production (32.4% maize). Mean NDVI fell from 0.303 (2000) to 0.263 (2008) before reaching 0.372 in 2024. Although recovered, 62.31% of it is degraded, particularly in outskirts, resulting from low level enforcement.

Forest degradation in Mudi Forest Reserve results from interacting socioeconomic pressures and ineffective management. Strengthening participatory forest governance, improving enforcement capacity and expanding alternative livelihood and household energy options are necessary to reduce degradation and enhance forest recovery.

INTRODUCTION

Forest degradation continues to be one of the most common causes of biodiversity loss, reduction of ecosystem services and increased vulnerability to climate change, especially for tropical developing nations where forests are still a source of livelihoods and fuel for cities (FAO, 2020). Although the main role of protected forests is to ensure ecosystem sustainability, many protected areas still suffer from vegetation reduction due to the failure of conservation strategies in addressing socioeconomic factors that cause resource exploitation. In Sub-Saharan Africa, dependence on biomass fuel and agricultural development has been identified as factors that cause unsustainable forestry practice despite the legislative framework being in place (World Bank, 2022; Dimnwobi et al., 2023).

Malawi is one of the most biomass fuel-dependent countries in the region, since firewood and charcoal are the key sources of energy for domestic purposes (World Bank, 2022). These factors have led to increased pressures on the forests that are in proximity to urban settlements because of urbanisation, population growth and poverty. Hence, forests that are under protective regimes suffer from illegal logging, charcoal-making, agriculture and resource extraction, which lead to the degradation of the forest cover (FAO, 2020; Chilinde & Mamiwa, 2022). An example of such challenges is Mudi Forest Reserve due to its proximity to Blantyre, which puts it at the risk of perpetual demands for land, timber and household energy sources, and institutional constraints restricting the protection of the reserve effectively (Prabhu & Branch, 2023).

Theoretical frameworks like Political Ecology point to an issue of governance failure and structural inequalities as an explanation for environmental change rather than merely a consequence of local poverty (Blaikie & Brookfield, 2015; Robbins, 2019). This view focuses on the role of energy poverty and weak enforcement in unsustainable resource utilization in the context of the Mudi Forest Reserve. The Sustainable Livelihoods Framework (SLF) proposes that, at the household level, people rely on natural resources as a sensible way to survive lacking alternatives to access to capital (Chambers & Conway, 1992; Scoones, 1998). Theories both together speak of forest degradation as a multi-scalar phenomenon where macro level institutional factors affect the micro level decisions of the households regarding how they survive.

Socio-economic activities in the region, related to income generation and domestic energy requirement are the primary drivers of forest loss. The results of the study suggest that some 49.1% of the respondents have been cutting trees on purpose to make

money and 59.6% have deforested land for farming. The agricultural activities following such clearing is still dominated by maize with 32.4% of cultivation. Furthermore, energy poverty is also a significant problem in Malawian context as 62.6% of the population directly uses firewood, either due to financial accessibility, or lack of electricity (World Bank, 2022).

Limited resources, weak law enforcement and lack of community participation are significant constraints on the effectiveness of current forest management. Contemporary management strategies tend to focus on criminalizing lawlessness, instead of focusing on the socioeconomic needs of the neighbouring communities (Corbera et al., 2020). There is a statistically significant relationship between the length of stay and perceptions of the lack of forest protection (e.g., lack of signs, lack of knowledge about regulations; $X2 = 10.634$, $p = 0.022$). ultimately, management effectiveness is based on the ability to adopt co-management systems that bring together the two concepts of community stewardship and energy Chepkemoi and Musya (2023).

Although previous studies have documented individual drivers of forest degradation, most have examined either socioeconomic pressures or management interventions independently. Similarly, the literature that uses remote sensing has, to a large extent, measured vegetation change without considering the satellite evidence, as well as the household perceptions and institutional performance as the explanation behind the continued degradation. This has constrained the knowledge of the processes by which livelihood dependence and management effectiveness interplay to yield long-term results that determine forest condition, especially in the peri-urban protected forests like Mudi.

This study bridges this gap by combining evidence based on household survey, key informant interview and long-term analysis of the normalized difference vegetation index (NDVI) to analyse the joint contribution of socioeconomic drivers and management effectiveness in forest degradation in Mudi Forest Reserve. By establishing connections between community-level drivers and the institutional capacity, and vegetation trends that are observed independently, the study can offer a more detailed account of forest degradation than methods that depend only on social or remote sensing indicators. The findings provide evidences to guide integrated forest management initiatives to help meet the livelihood demands, governance loopholes, and conservation of forests in the long run in Malawi and other similar peri-urban forest reserves.

MATERIALS AND METHODS

Study Area

The study was conducted in Mudi Forest Reserve, located in Blantyre District in southern Malawi. Established primarily to protect the Miombo woodland ecosystem and associated biodiversity, the reserve also provides ecosystem services including carbon sequestration, watershed protection, microclimate regulation and recreational opportunities. Due to its close proximity to the city of Blantyre, the reserve is exposed to continuous anthropogenic stress due to fast urban growth, rising biomass energy requirements, agricultural encroachment and unlawful mining of forest products (see Fig. 1 for details).

Such conflicting ecological and socioeconomic factors precondition Mudi Forest Reserve as an appropriate site to investigate the relationship between livelihood-oriented consumption of resources, the extent of forest management effectiveness, and vegetation transformation. The reserve was chosen as it is one of the peri-urbanized protected forests in Malawi, where conservation goals are becoming more conflict-ridden with the resource needs of surrounding communities, and thus offers an opportunity to assess the drivers and management of forest degradation.

Study Design

To investigate socioeconomic drivers, assess the effectiveness of forest management and assess long-term vegetation change in the Mudi Forest Reserve, the study used a convergent mixed-methods design which incorporated household surveys, key informant interviews, field observations and satellite-based remote sensing.

Sample Size and Sampling Techniques

The sample size of the study was 171 respondents. This was done from a population of 300 community members living around Mudi Forest Reserve. This population was identified for their proximity, period of stay, resource dependence with the guidance of

local community leadership documents that provided information about households that interacted directly or relied on the forest. The number of samples was determined according to the formula of Taro Yamane:

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

1

where n is the sample size, *N* is the population size (300) and *e* is the standard error at a 95% confidence interval (0.05). Plugging in the numbers to the formula:

$n = \frac{300}{1+(300\times\ 0.05^2)}$ =171, This led to 171 respondents being used for the study.

Software and Tools

Satellite image processing and NDVI generation were conducted using Google Earth Engine (GEE), while QGIS was used for spatial processing, map production and vegetation classification. The quantitative survey data were analysed using IBM SPSS Statistics and the qualitative interview responses were equated and analysed with the use of thematic analysis. Microsoft Excel was used for data cleaning, descriptive summaries and graphical presentation of NDVI trends. The integration of social and geospatial datasets enabled triangulation of socioeconomic, institutional and ecological evidence.

NDVI Calculation

Some of the vegetation dynamics were determined by the Normalised Difference Vegetation Index (NDVI) of cloud-free Landsat imagery acquired between 2000 and 2024. Landsat 5 TM, Landsat 7 ETM + and Landsat 8/9 OLI datasets were accessed through Google Earth Engine to ensure temporal consistency. After image pre-processing, including cloud masking and radiometric correction, NDVI was computed from the near-infrared (NIR) and red spectral bands using the standard equation:

$$\mathrm{NDVI}\ = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

2

Annual mean NDVI values were generated to evaluate long-term vegetation trends, while NDVI outputs were reclassified into four vegetation condition classes to examine changes in forest health over time. The resulting spatial and temporal analyses were used to validate field observations and determine whether vegetation change corresponded with the socioeconomic pressures and management conditions identified during household and key informant surveys.

Data Analysis

Quantitative data were analysed using descriptive statistics, including frequencies, percentages and mean scores, to identify dominant socioeconomic drivers and assess perceptions of forest management effectiveness. Qualitative data were analysed thematically to explain institutional and community experiences. NDVI time-series and vegetation class analyses were interpreted alongside social data to establish relationships between observed vegetation change, livelihood activities and management performance, thereby strengthening the validity of the study through methodological triangulation.

RESULTS AND DISCUSSION

The results show that socioeconomic activities are the main cause of forest degradation in Mudi Forest Reserve and that the activities still pressurize forest resources even though management interventions are in place. The observed vegetation dynamics from NDVI analysis corroborate respondents' perceptions, thus suggesting that anthropogenic activities have contributed to measurable changes in forest condition over the last two decades. This integrated evidence shows that the issue of forest

degradation in the forest is not purely an ecological issue, but rather a result of the socioeconomic reliance on forest resources and constraints on forest governance (Chambers and Conway, 1992; Gardner et al, 1990).

The socioeconomic evaluation found that charcoal production, firewood gathering, illicit logging, agricultural encroachment and livestock grazing were the leading causes of forest degradation (see Fig. 2 for details). These livelihoods indicate high reliance of the surrounding populations on forest resources as household fuel and income-generating activities, which is a common trend in rural livelihoods in Malawi and other Miombo woodland ecosystems (Piabuo et al., 2021; Boakye, 2020). The biomass extraction preponderance indicates that poverty, coupled with the lack of decent jobs and lack of other sources of energy, still shapes household choices in deciding on how to use the forest resources. The same sentiment was received by Eshetu & Tesfaye (2024), who concluded that household reliance on fuelwood and charcoal was still one of the best predictors of forest degradation in Malawi. In addition, according to Piabuo et al. (2021), the rise in the urban demands for charcoal creates more pressure on the peri-urban forests or forest reserves that are situated near the towns such as Blantyre. In terms of land use, most respondents (59.6%) cleared forested regions to produce crops.

The location of Mudi Forest Reserve, adjacent to Blantyre City, further increases its vulnerability to commercial exploitation. Along with subsistence demand, forest products are becoming more and more important in the urban energy markets, hence leading to a higher rate of illegal harvesting and forest disturbance. Through agricultural encroachment and livestock grazing, the pressure is enhanced by lowering vegetation cover and blocking the regenerative process of natural forests. The findings align with other past research that has pointed to agriculture advancement, fuelwood harvest and poor land-use planning as key contributors to forest degradation in Southern Africa (Fatch et al., 2021; Chilinde & Mamiwa, 2022). These findings as shown in Fig. 2 thus indicate that it is the interaction of various and interrelated socioeconomic factors that leads to forest degradation and not a single activity.

Statistical Associations of Resident Duration and Forest Activities

The period of stay for residency was a significant factor in certain forest interactions in the study. There is a significant association between length of stay and the reason for hunting animals ($\chi 2 = 18.261$, $p = 0.019$) where long-term residents (more than 20 years) had higher rates of fun (25.2%) and medicine (5.3%). In addition, perceptions of gaps in forest protection were significantly correlated with length of residence ($\chi 2 = 10.634$, $p = 0.022$), such that longer-term residents were more likely to think that there were a lack of forest signs and educational programs as serious failures.

The evaluation of forest management effectiveness disclosed that despite the fact that the respondents have acknowledged the presence of forest conservation interventions, the interventions have failed to achieve the necessary level of reducing the underlying factors contributing to degradation. Weak law enforcement, inadequate patrols, limited financial and human resources, insufficient community participation and low awareness of forest regulations were identified as major constraints affecting management effectiveness (see Fig. 4 for details). Such results suggest that the prevailing management strategies have been more focused on limiting unlawful behaviors instead of taking action to deal with the socioeconomic aspects driving the need to remain in a state of persistent reliance on forest resources. Similar results were found by Corbera et al. (2020) who noted that conservation policies have little chance of becoming sustainable when the neighboring communities have no viable livelihood options. On the same note, Chepkemoi & Musya (2023) found that the lack of institutional capacity and effective stakeholder relations complexity lowers compliance with forest management laws.

The continuity of illegal extraction of the resources even when the management interventions are provided, shows that the management effectiveness must be assessed not only by the presence of conservation policies but also by their effectiveness in minimizing the socioeconomic factors contributing to the degradation. This result affirms the Sustainable Livelihoods Framework, where households are identified to rely on natural resources in an environment where alternative means of livelihood are scarce, and Political Ecology, where governance frailties and institutional constraints are entrenched in relation to enhancing unsustainable resource utilization (Chambers and Conway, 1992; Scoones, 1998; Peluso and Vandergeest, 2011). As a result, it is unlikely that increased enforcement, with no accompanying effort to improve livelihoods at the community level, will generate sustainable forest degradation reductions.

The socioeconomic findings are backed up by the NDVI analysis, which yields independent ecological evidence. The values of the mean NDVI decreased in 2000–2008 and then began to rise slowly between 2008 and 2024, thus indicating an initial deterioration

in vegetation condition followed by partial recovery (see Fig. 5 for details). Early monitoring period decline is linked with increased disturbance of forests in charcoal production, fuelwood gathering, illegal logging and agricultural encroachment reported by the respondents. The same association between anthropogenic activities and reduced vegetation greenness has been reported in forest ecosystems where agricultural expansion and human pressure contribute to vegetation decline and forest loss (Hinderer et al., 2024; Magalhães, 2023).

Despite the improvement of the NDVI values after 2008, the recovery was slow, thus indicating forest regeneration has taken place but this has not completely offset the past degradation. The observed improvement may reflect natural regeneration together with forest restoration initiatives implemented within the reserve. Nevertheless, the extraction of forest resources seems to have limited the complete reestablishment of vegetation suggesting that management interventions were partially successful. Olagunju *et al.* (2024) also reported similar post-disturbance recovery patterns, thus stating that vegetation recovery in conserved forests is slow in the presence of anthropogenic disturbances.

To further evaluate vegetation dynamics, NDVI values were classified into four vegetation health categories representing very low, low, moderate and high vegetation density (see Table 2 for details).

Table 2
NDVI Classification

NDVI Class	NDVI Range	Description
Very Low	< 0.2	Degraded areas with no vegetation
Low	0.2–0.4	Sparse vegetation
Moderate	0.4–0.6	Healthy Vegetation
	> 0.6	Dense Vegetation
Figure 6: NDVI Classification Maps Over Time		

The classification maps (see Fig. 6 for details) show that vegetation condition deteriorated markedly in 2008, with increases in very low vegetation classes and reductions in moderate and high vegetation cover. Subsequently, there was a gradual increase in moderate vegetation between 2016 and 2024, which shows slow ecological restoration. Nonetheless, low vegetation still happened to be the major land-cover type in the course of the study.

Table 3
NDVI Class Distribution

NDVI Class	2000		2008		2016		2024	
	Area (Ha)	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**
High (> 0.6)	1.55	0.17%	0.09	0.01%	16.71	1.84%	27.05	2.98%
Moderate (0.4–0.6)	107.59	11.85%	34.8	3.83%	133.43	14.70%	315.03	34.71%
Low (0.2–0.4)	723.53	79.72%	669.69	73.79%	721.46	79.49%	502.66	55.38%
Very Low (< 0.2)	74.95	8.26%	203.04	22.37%	36.02	3.97%	62.88	6.93%
Total	**907.62**	**100%**	**907.62**	**100%**	**907.62**	**100%**	**907.62**	**100%**

The NDVI class statistics (for details see Table 3) reinforce these observations. Low vegetation occupied approximately 79.7% of the reserve in 2000 and remained dominant until 2024 despite a notable increase in moderate vegetation during the later years. Dense vegetation never represented more than 3 percent of the reserve, showing the fact that vast areas of the forest are in a barren condition. These results suggest that although conservation treatments could have reduced the extent of vegetation loss and certain regeneration could have occurred, they have not so far been able to replenish the reserve to a healthy vegetation condition. On the whole, the socioeconomic evidence combined with NDVI analysis shows a distinct connection between reliance of households on forest resources, restrictions on management and vegetation degradation over time. The conservation of Mudi Forest Reserve on a sustainable basis will thus involve interventions that will not only handle the rural livelihood but also facilitate

the low-cost sources of energy, reinforce the institutions that will enforce the conservation process, as well as increase community involvement in the management of the forest (Chambers and Conway, 1992; Corbera, 2020).

CONCLUSION AND RECOMMENDATIONS

The study demonstrates that forest degradation in Mudi Forest Reserve is primarily driven by socioeconomic pressures, particularly charcoal production, firewood collection, illegal logging, agricultural encroachment and livestock grazing. These activities, reinforced by household dependence on forest resources and inadequate alternative livelihood opportunities, continue to undermine forest conservation efforts. Even though the available management interventions have played a role in restoring the vegetation at slow rates, as measured by the improving NDVI values since 2008, the observed persistence of low vegetation classes is an indication that the management performance is still limited by poor enforcement, lack of community involvement, and poor institutional capacity to carry out the performance. To achieve sustainable restoration and long-term conservation of the Mudi Forest Reserve, the integration of socioeconomic interventions and enhanced forest governance is therefore critical.

Forest management must incorporate more vigorous law enforcement with community-based conservation, alternative livelihood programmes and affordable clean energy projects to decrease reliance on forest resources. Field-based management should be complemented by continuous NDVI monitoring to assess the recovery of the vegetation and guide adaptive conservation in the Mudi Forest Reserve.

Declarations

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Ethical Approval

The study was conducted following all the necessary ethical guidelines that govern studies where human beings are involved as participants. This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Ethical approval for the study protocol and data collection instruments was granted by the Malawi University of Business and Applied Sciences (MUBAS) through the academic committee, school board and then ethics committee. MUBAS has its own ethics committee called the MUBAS Research and Ethics Committee (MUBASREC) that oversees, advises, and approves all research conducted by members of staff and students. The study was approved by the Blantyre City Council and the Department of Forestry to conduct collect data in MUDI Forest. Before the field surveys started, formal authorization to carry out the research had been granted by the leadership of the local communities around the Mudi Forest Reserve.

Consent to Participate

All the participants were made aware of the objective of the research, and prior informed consent was obtained from all the respondents before collecting the data. To protect the participants, the information collected from them was kept highly confidential, and the anonymity of the respondents was maintained at all times.

Declarations
of conflict

Consent To Publish

Not applicable

Animal Permission

Not applicable

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Author Contribution

Author contributionsFollowing the Contributor Roles Taxonomy (CRediT) typically utilized by Springer journals:• Precious Puzani: Conceptualization; Methodology; Formal analysis; Investigation; Data Curation; Writing - Original Draft; Visualization.• Brighton Austin Chunga: Methodology; Writing - Review & Editing; Validation.• Harold Wilson Tumwitike Mapoma: Conceptualization; Resources; Writing - Review & Editing; Supervision; Project administration; Corresponding Author.

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Data Availability

The datasets generated during this study and/or those analysed during the study are not publicly available due to its sensitivity regarding participants information but available from corresponding author upon reasonable request. The satellite imagery used in this study was publicly available from USGS and accessed and processed using Google Earth Engine.

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Figures


Mudi Forest Reserve Catchment Area, Blantyre City, Southern Malawi
Kyambadwe
Ndirande
Mbayani
Mbayani Forest Reserve
Mbayani Stream
Mbayani Road
Mbayani Drive
Mbayani Primary School
Mbayani Health Centre
Mbayani Trading Centre
Mbayani Market
Mbayani Police Post
Mbayani Community Day Secondary School
Mbayani Community Day Primary School
Mbayani Community Day Secondary School
Mbayani Community Day Primary School
Mbayani Community Day Secondary School
Mbayani Community Day Primary School

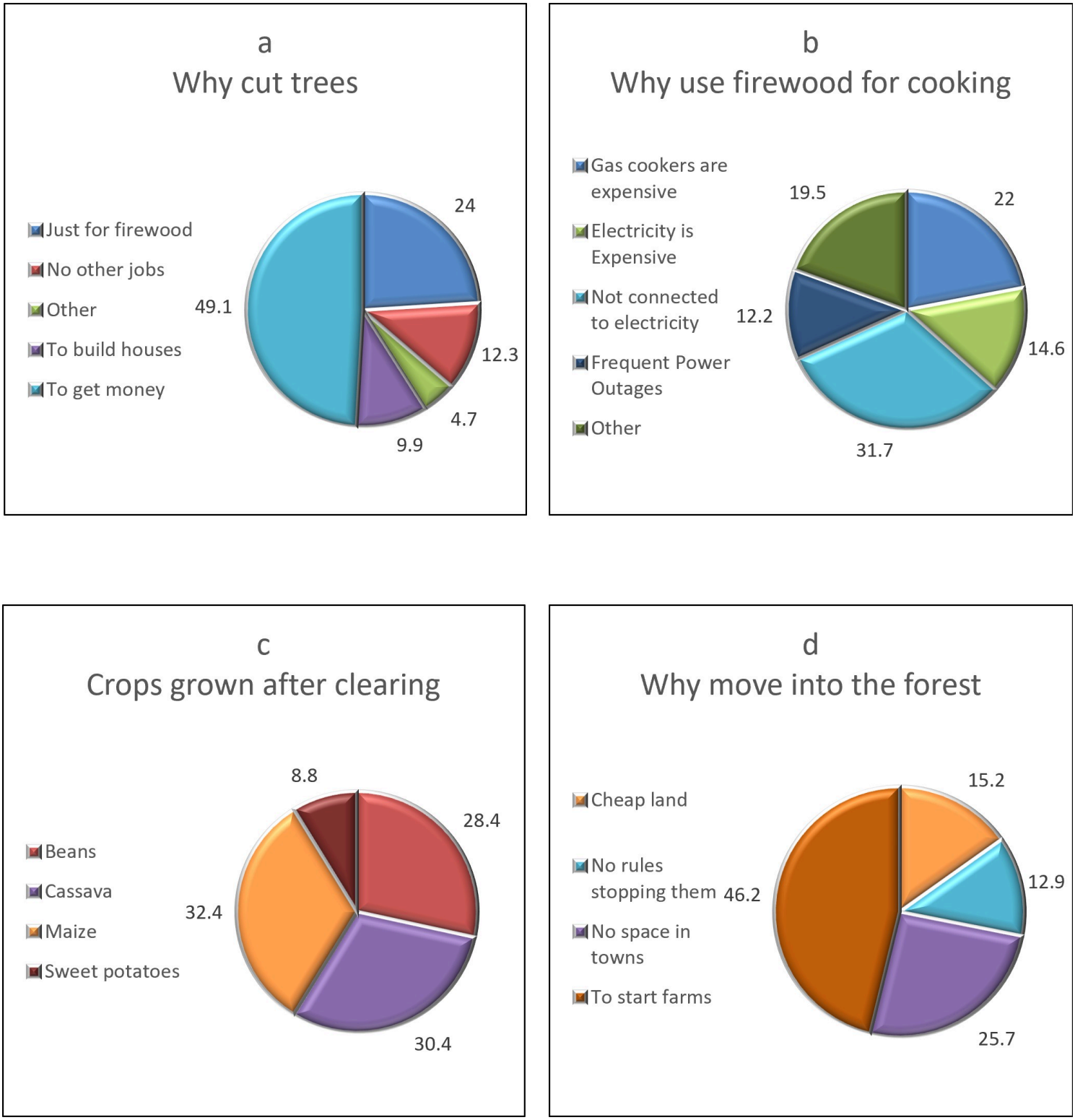


Figure 2

Figure 2: Socioeconomic activities contributing to forest degradation

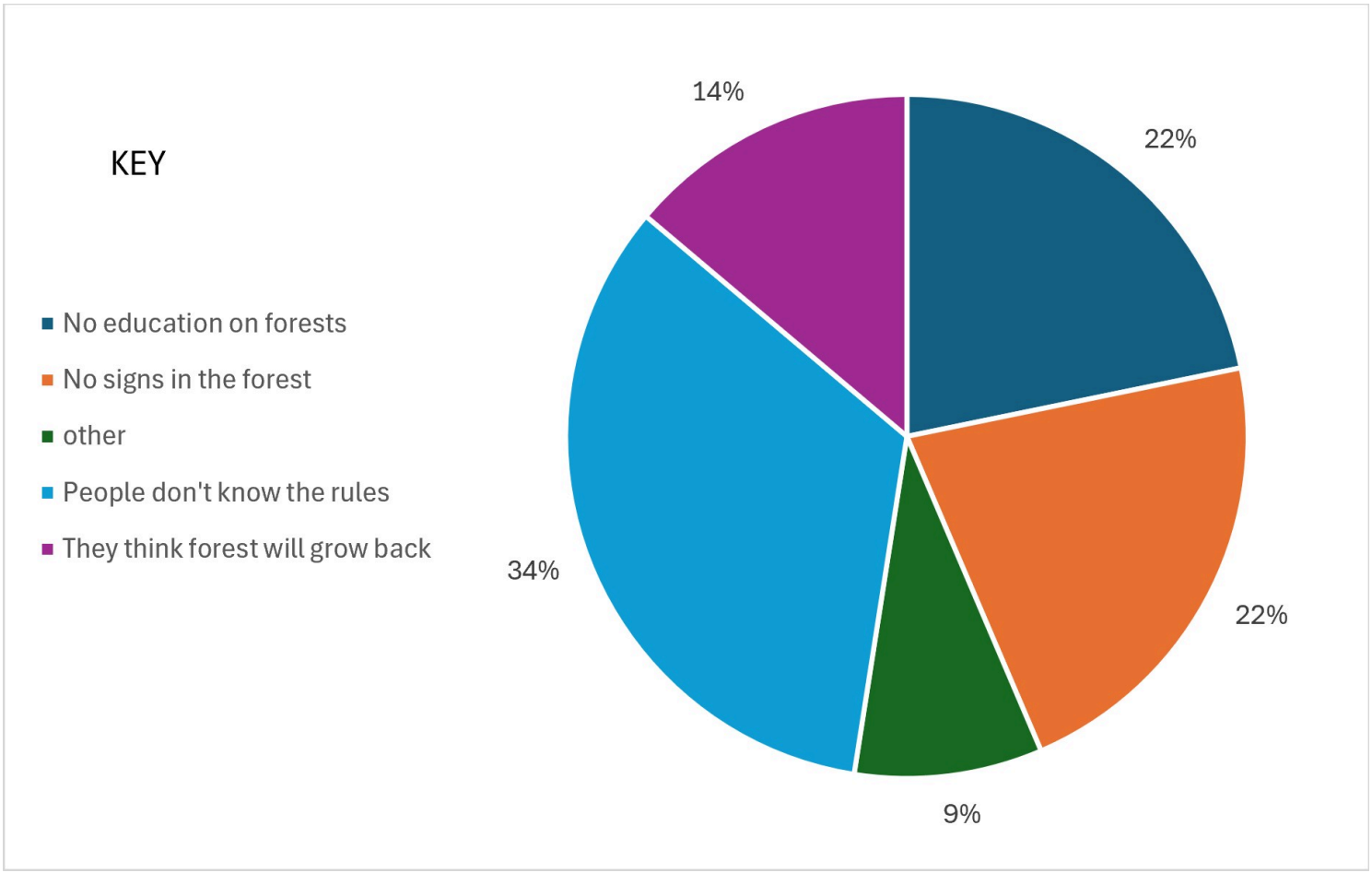


Figure 3

Figure 4: Gaps in forest protection: inadequacies in policies, enforcement and community involvement

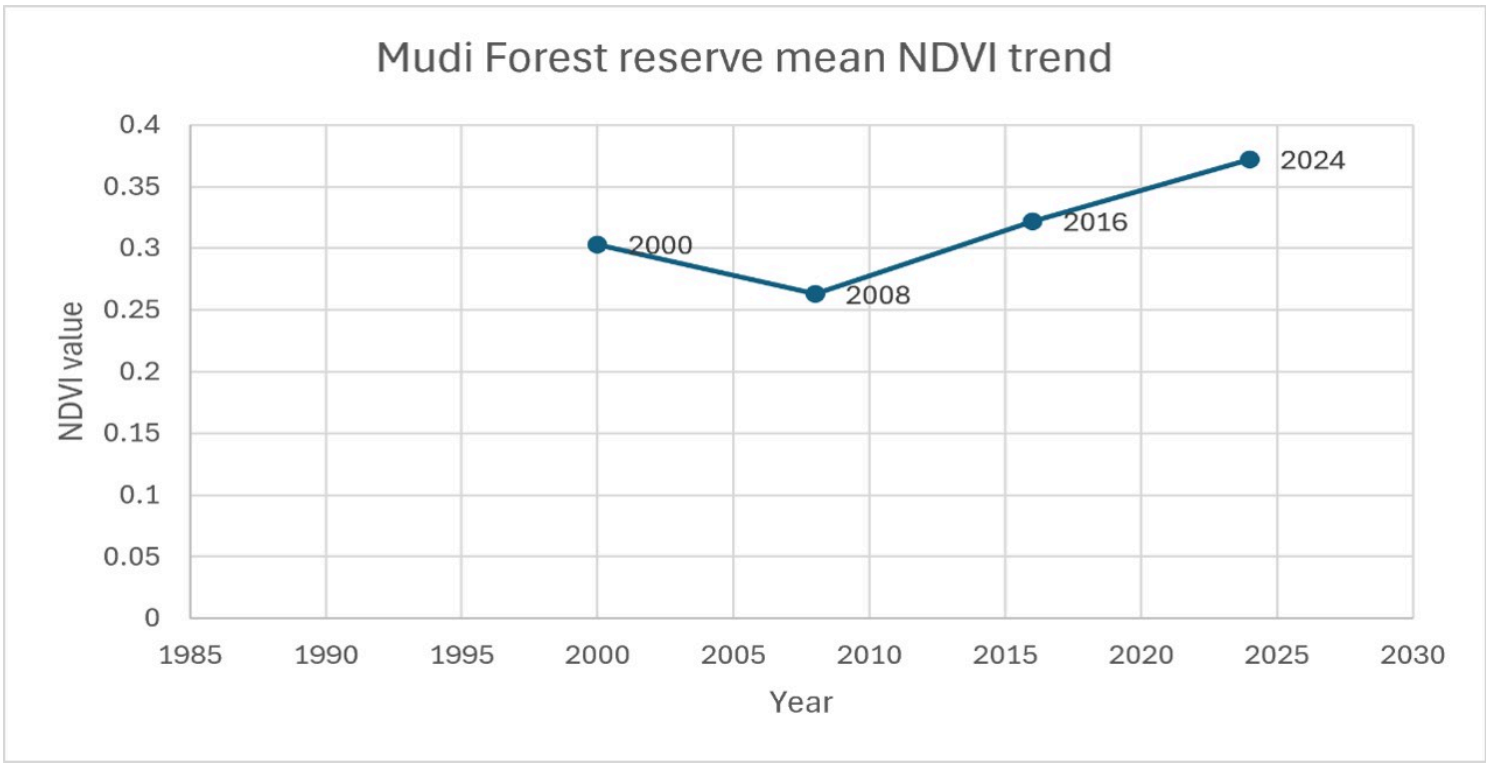


Figure 4

Figure 5: Mean NDVI Trends (2000–2024)

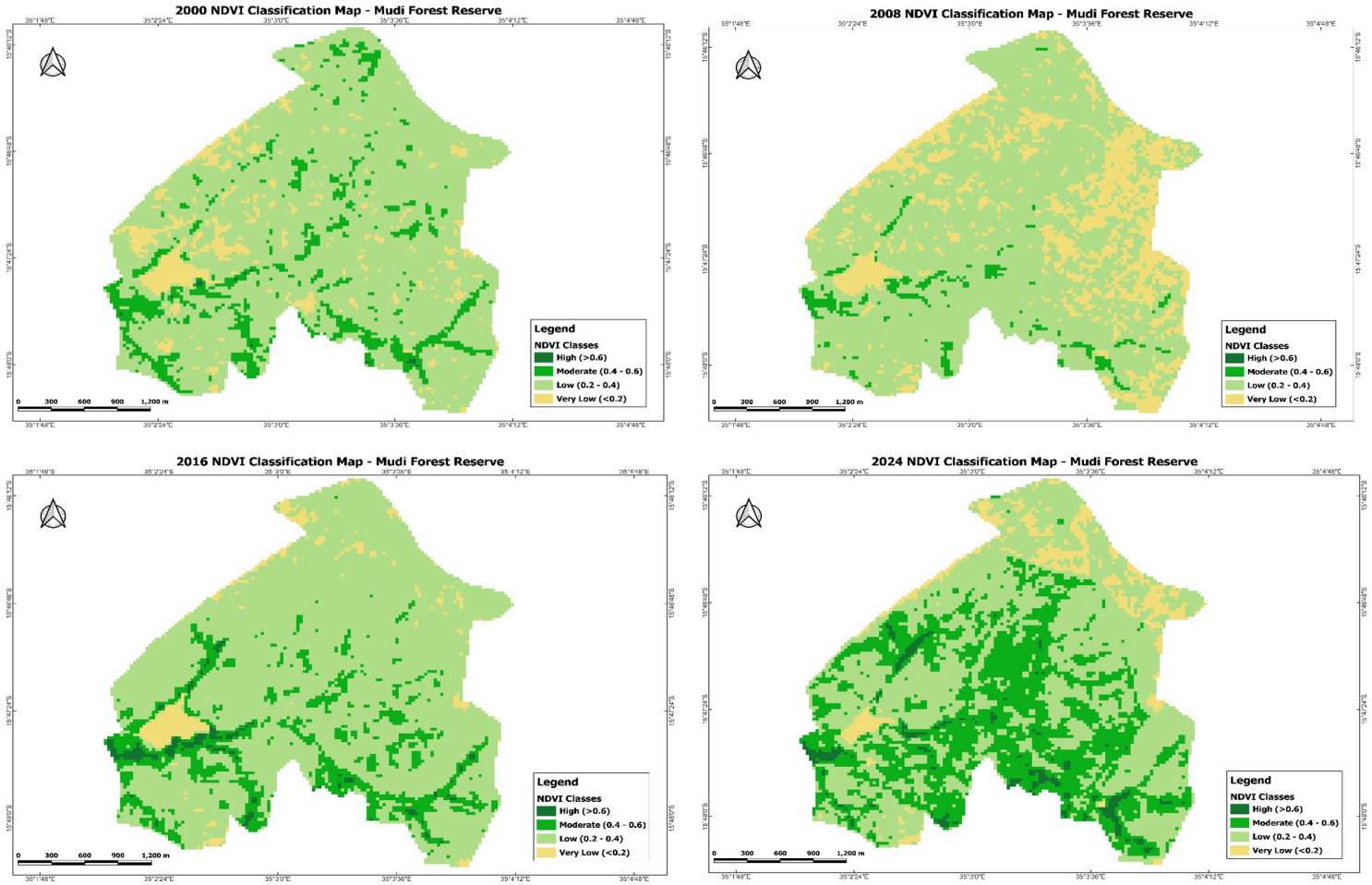


Figure 5

Figure 6: NDVI Classification Maps Over Time