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Original Article

Forest Cover Dynamics in Ngarama North Forest Reserve, Kilwa District, Tanzania

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ABSTRACT

Understanding forest cover dynamics is important for supporting Sustainable Forest Management strategies and implementing climate change mitigation policies. Remote sensing and geospatial analysis play a critical role in mapping and characterizing forest conditions in protected areas. In Tanzania, where management practices have evolved over decades, remote sensing is essential for assessing their effectiveness. Ngarama North Forest Reserve, which transitioned its management regime from the Forestry and Beekeeping Division (FBD) to the Tanzania Forest Service Agency (TFS), has been affected by this transformation. However, no prior study has evaluated the impact of this management shift on forest cover conditions. This study used Landsat imagery from 2000, 2010, and 2020 to classify forest cover via supervised image classification with the random forest algorithm on Google Earth Engine and monitored the rate of change in forest cover classes over time. Additionally, Key informant interviews and focus group discussions with forest officials and nearby forest communities provided insights into drivers of forest cover change, complementing the spatial data obtained. The results show that in 2000, the forest comprised 33.47% closed forest, 40.99% open forest, 21.61% bushland, and 3.94% bare land. By 2010, these proportions shifted to 16.19%, 57.30%, 23.47%, and 3.03% respectively. In 2020, the proportions changed again to 39.29%, 26.70%, 30.02%, and 3.99% respectively. These shifts suggest a complex interplay of environmental management, land use changes, and ecological responses. The key drivers behind these trends include illegal logging, uncontrolled wildfires, grazing, hunting, farming and natural factors. The findings of this study show that forest conditions have significantly improved over time due to the shift in management regime from FBD to TFS. This study provides crucial insights for sustainable forest management strategies and climate change mitigation policies by demonstrating the positive impact of management regime changes on forest conditions over time.

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INTRODUCTION

Protected Areas (PAs) including National Parks, Forest Reserves, and other conservation designations, exhibit significantly lower deforestation rates compared to unprotected landscapes (Gizachew et al., 2020). The global network of protected areas expanded significantly between the 1970s and the 2000s, particularly in developing countries where there is a high level of biodiversity (Naughton-Treves et al., 2005). During this period, the number of designated PAs increased more than tenfold, resulting in the protection of approximately 1.9 billion hectares of land worldwide (Ramírez & Santana, 2019). Recognizing the importance of PAs, the Tanzanian government in the 1990s designated around 43% of its forested land for various forms of protection (Ract et al., 2024).

In Tanzania, over the past 25 years, efforts have been made to identify and upgrade biologically significant reserves into Nature Forest Reserves (NFRs). Since independence up to 2010, the management of forests under the Central Government in Tanzania was under the Forestry and Beekeeping Division (FBD) of the Ministry of Natural Resources and Tourism. In 2011, there was a shift in the management of these forests by the Tanzania Forest Services (TFS) Agency (URT, 2019). The ecological and economic value of forests across different ownership structures emphasizes the necessity for sustainable management; however, in many developing countries like Tanzania, the effectiveness of institutional power transfers remains ambiguous (Ract et al., 2024; Manyanda et al., 2021).

Comparative studies assessing the effectiveness of PAs globally reveal mixed outcomes regarding their ability to prevent deforestation (Gizachew et al., 2020; Ract et al., 2024). This variability can be attributed to a range of ecological, socioeconomic, and institutional factors, including the type of PA involved (Nzunda & Midtgaard, 2017). Understanding land use and cover changes (LUCC) is crucial for grasping global biogeochemical processes, predicting future conservation scenarios, and informing policies on biodiversity conservation and forest sustainability (Cisneros-Araujo et al., 2021; Nzunda & Midtgaard, 2019). This information is particularly vital for tropical countries, where significant biodiversity is concentrated in forests and grasslands that are undergoing rapid land use changes (Nzunda & Midtgaard, 2019). Recent advancements in remote sensing technology provide valuable insights into LUCC due to their extensive temporal and spatial coverage (Horning et al., 2010; Kimaro & Chidodo, 2021; Reith et al., 2021; Tewkesbury et al., 2015). Utilizing such data is essential for evaluating the effectiveness of forest management in developing countries like Tanzania, where various management practices have been implemented over decades (Manonga, 2013; Manyanda & Kashaigili, 2022).

The Ngarama North Forest Reserve is crucial for both environmental and socioeconomic stability, as it provides essential ecosystem services, serves as a buffer against climate change impacts,

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supports biodiversity, and offers resources like timber and non-timber products that enhance the livelihoods of surrounding communities. The Forest has undergone a significant shift in its management system, transitioning from the Forestry and Beekeeping Division (FBD) to the Tanzania Forest Service (TFS), and ultimately adopting a paramilitary mode of operation. This transition raises concerns about potential changes in forest cover under different management regimes. However, no previous studies have assessed how these management changes impact forest cover conditions. To address the gap, this study employs remote sensing data to analyze forest cover dynamics during both management periods.

The objectives of the study include:

- To classify and map LUCC in the Ngarama North National Forest Reserve for 2000, 2010, and 2020.
- To quantify the persistence and trajectories of LUCC during the study period.
- To identify and assess the drivers of forest cover change in the study area.

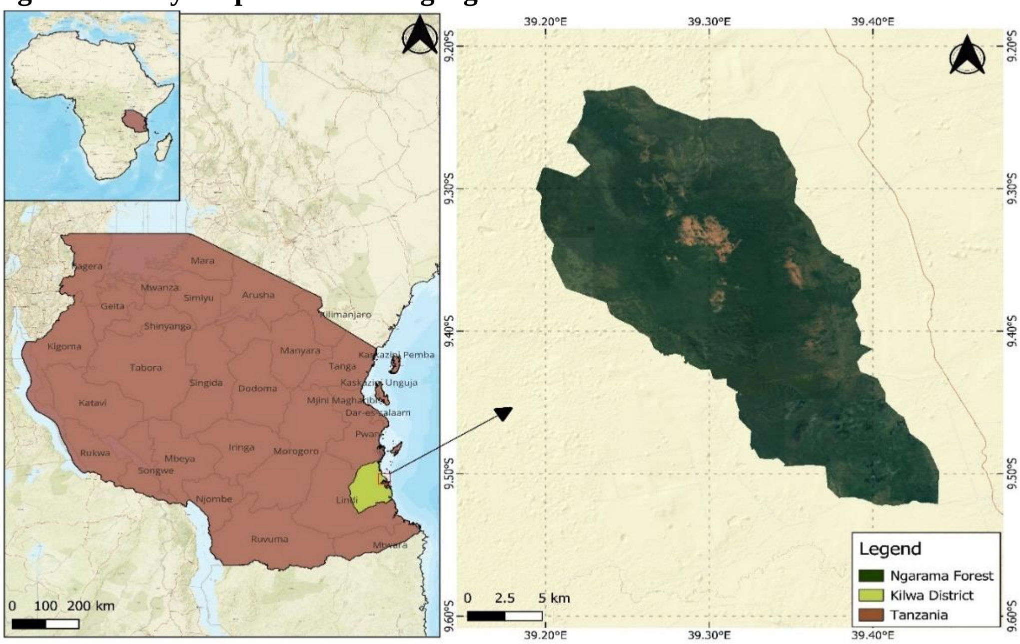
MATERIALS AND METHODS

Study Area

The study was conducted in Ngarama North Forest Reserve with an area of 42,893.70 hectares, located in Kilwa District – Tanzania, as shown in Figure 1. The Forest is characterized by a hot and humid climate whereby an average annual temperature is approximately 27.1°C, with temperatures ranging from 22°C to 30°C throughout the year. Rainfall is bimodal, occurring mainly from November to April, with annual precipitation varying between 800 mm and 1,400 mm and an average of 912 mm. The forest reserve is bordered by Kiwawa, Mandawa, Hotel Tatu, Mirumba, and Mtandi villages to the east, and Makangaga to the southwest and it is accessible via a main route from Kilwa Masoko Town, which is about 112 to 130 km away depending on the path taken.

The ecological environment of the forest is influenced by its geographical location and climatic conditions, which support diverse flora and fauna. The area experiences dry spells, particularly at the end of January or early February, impacting the local ecosystem. The forest's boundaries are marked by curvilinear and cut lines, integrating it into the surrounding landscape and communities. This reserve plays a crucial role in maintaining biodiversity and supporting local livelihoods through its natural resources.

Figure 1. Study Map Area Showing Ngarama North Forest Reserve



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Data Collection and Processing

Image Acquisition

Imagery from 2000, 2010, and 2020 was collected automatically via the USGS (United States Geological Survey) through the GEE (Google Earth Engine) platform's data catalogue, as detailed in Table 1. This study utilized observations from these distinct time points to conduct a comprehensive examination of trends, with the 2010 observation enhancing the trend line positioned between 2000 and 2020.

Notably, more images were available during the dry season due to the higher likelihood of obtaining less cloudy imagery compared to the wet season. Consequently, images with cloud cover of less than 10% were selected and filtered. These selected images were then combined into a single image using a median filter function.

Table 1. Selected Landsat Imagery for Land Cover Classification in 2000, 2010 and 2020

2000			2010			2020		
Source	**n**	**date (mm/dd)**	**Source**	**n**	**date (mm/dd)**	**Source**	**n**	**date (mm/dd)**
Landsat 5	1	22/05/2000	Landsat 5	1	17/03/2010	Landsat 8	1	03/04/2020
	2	29/05/2000		2	10,17/05/2010		3	09,16,23/08/2020
	2	30/06/2000					1	01/09/2020
	1	02/09/2000						
Total image found	**6**			**3**			**5**	

Image Processing and Classification

Composite imagery was obtained for each year by spectrally harmonizing Landsat 5 imagery with the Landsat 8 series using a linear transformation. To enhance image quality, the *Fmask* algorithm was applied to mask out clouds and their shadows. Each composite image was aligned using a *visual image param*, followed by clipping to the region of interest (Reith et al., 2021). Ground truth data for land cover classification were gathered through visual interpretation from platforms such as Google Earth, Google Street View, and OpenStreetMap, leveraging their accessibility and high-quality imagery (Loukika & Keesara, 2021; Nguyen, 2020).

Based on local knowledge, the study categorized land cover into four classes: closed forest, open forest, bushland, and bare land. A total of 690 reference data points were collected in 2000, 720 in 2010, and 650 in 2020. Supervised classification was performed using the Random Forest (RF) algorithm with ten decision trees. Of the ground truth data collected, 70% was allocated for training and 30% for validation. The classification accuracy was evaluated through overall accuracy, producer's accuracy, and user's accuracy, using a confusion matrix (Nguyen, 2020).

The final classified images were exported to Google Drive for further analysis. The methodological flow of image classification is illustrated in Figure 2. This structured approach not only ensures a robust classification process but also facilitates reliable land cover mapping over the years analyzed.

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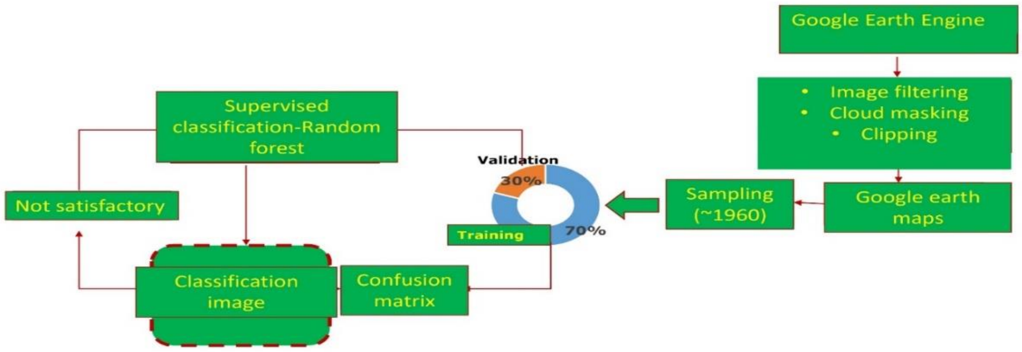
Figure 2. Flow Chart of Land Cover Classification



Source: Own Elaboration

Image analysis

Post-classification filtering and change detection were performed using QGIS software version 3.32 to assess land cover changes across three temporal snapshots: 2000, 2010, and 2020. The assessment identified gains and losses in land cover classes for the periods 2000-2010 and 2010-2020 by examining the off-diagonal entries in the cross-tabulation matrix through spatial overlay analysis. The persistence and trajectory of these changes were visualized using a chord diagram in R software. To quantify the annual rate of change (r) for each land cover class, the formula used by Nzunda & Midtgaard, (2019) and Pontius et al., (2004) was utilized in Microsoft Excel, expressed as:

$$\boldsymbol{r} = ((\mathbf{1}/\boldsymbol{t}\mathbf{2} - \boldsymbol{t}\mathbf{1}))\ \boldsymbol{x}\ \boldsymbol{ln}(\boldsymbol{A}\mathbf{2}/\boldsymbol{A}\mathbf{1})$$

Where *r* represents the annual rate of change, *t* is the number of years spanning the period (10 years for both intervals), and *A*2 and *A*1 denote the land cover class areas at the end and beginning of the evaluated period, respectively.

Drivers of Forest Cover Change

To obtain information on the drivers of forest cover change, Key Informant Interviews (KII) and Focus Group Discussions (FGD) were employed, utilizing open-ended questionnaires. KII were undertaken with four key informants at the district and zonal levels. This included the District Forest Conservator (DFC), the District Forest Officer (DFO), a retired DFO, and the Southern Zone Zonal Conservation Commissioner (ZCC). The Key informants were purposefully selected based on their forestry expertise, knowledge, and years of experience within the Forestry Department and the study area. In addition, three FGDs were conducted in randomly selected villages (Mtandi, Mandawa, and Hoteli Tatu) located adjacent to the forest reserve. Each discussion with 10 participants comprising three Village Natural Resources Committee members (VNRCs), two village council members, two elders, and three community members with knowledge about the forest reserve.

Ground truthing was performed in the study area by visiting 170 plots to verify qualitative data obtained from the Focus Group Discussions and Key Informant interviews. Ground truth data were collected with the help of a handheld Garmin Global Positioning System (GPS) and topographic sheets. The responses from both the interviews and FGDs were analyzed using content analysis. Finally, the frequency of driver's occurrences in each plot was quantified to provide a comprehensive analysis of the findings.

RESULTS

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Accuracy of Land Cover Classification for 2000, 2010 and 2020

The accuracy assessment shows that in 2000, 2010, and 2020, the random forest classifier achieved an overall accuracy and Kappa coefficient of over 80% and 75% respectively for each year (Tables 2, 3, and 4). Furthermore, the average user's accuracy and producer's accuracy for each class indicated that there was a higher degree of confusion between closed forest and open forest than between closed forest and bushland and between closed forest land and bare land for each respective year (Tables 2, 3, and 4)

Table 2. Confusion Matrix of Land Cover Classification for the Year 2000

CONFUSION MATRIX 2000						
	Closed forest	**Open forest**	**Bushland**	**Bare land**	**%**	**Average UA**
Closed forest	81.40	18.60	0.00	0.00	100	0.95
Open forest	6.45	80.64	12.90	0.00	100	0.66
Bushland	0.00	9.09	90.90	0.00	100	0.79
Bare land	0.00	5.88	11.76	82.35	100	1.00
Average PA	0.81	0.81	0.91	0.82	0.84	0.85
Overall accuracy			**0.84**			
Kappa coefficient			**0.78**			

Table 3. Confusion Matrix of Land Cover Classification for the Year 2010

CONFUSION MATRIX 2010						
	Closed forest	**Open forest**	**Bushland**	**Bare land**	**%**	**Average UA**
Closed forest	86.05	9.30	2.33	2.33	100	0.97
Open forest	2.70	78.38	18.92	0.00	100	0.69
Bushland	0.00	15.09	84.91	0.00	100	0.79
Bare land	0.00	3.23	12.90	83.87	100	0.96
Average PA	0.86	0.78	0.85	0.84	0.83	0.85
Overall accuracy			**0.84**			
Kappa coefficient			**0.78**			

Table 4. Confusion Matrix of Land Cover Classification for the Year 2020

CONFUSION MATRIX 2020						
	Closed forest	**Open forest**	**Bushland**	**Bare land**	**%**	**Average UA**
Closed forest	88.88	8.88	0.00	2.22	100	0.80
Open forest	31.25	68.75	0.00	0.00	100	0.79
Bushland	0.00	0.00	86.66	13.33	100	0.89
Bare land	0.00	5.4	13.51	81.08	100	0.81
Average PA	0.89	0.69	0.87	0.81	0.81	0.82
Overall accuracy			**0.82**			
Kappa coefficient			**0.76**			

Land Cover Classification

The analysis of forest cover over the two decades revealed significant changes in forest cover categories within the study area as illustrated in table 5. In 2000, the forest cover composition was as follows: open forest comprised 40.99%, closed forest accounted for 33.47%, bushland represented 21.61%, and bare land made up 3.94% (Figure 3). By 2010, the distribution shifted markedly, with open forest increased to 57.30%, bushland decreased to 23.47%, closed

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forest declined to 16.19%, and bare land slightly reduced to 3.04% (Figure 3).

In 2020, the trend continued, with open forest decreased to 26.7%, bushland increased to 30.02%, closed forest rising significantly to 39.29%, and bare land remained relatively stable at 3.99% (Figure 3). Notably, between 2000 and 2010, the closed forest area decreased by a factor of 15; however, it experienced a two-fold increase from 2010 to 2020 (Figure 3).

Figure 3. Land Cover Classification and Percentage of Land Cover Classes for Ngarama North National Reserve in 2000, 2010, and 2020.

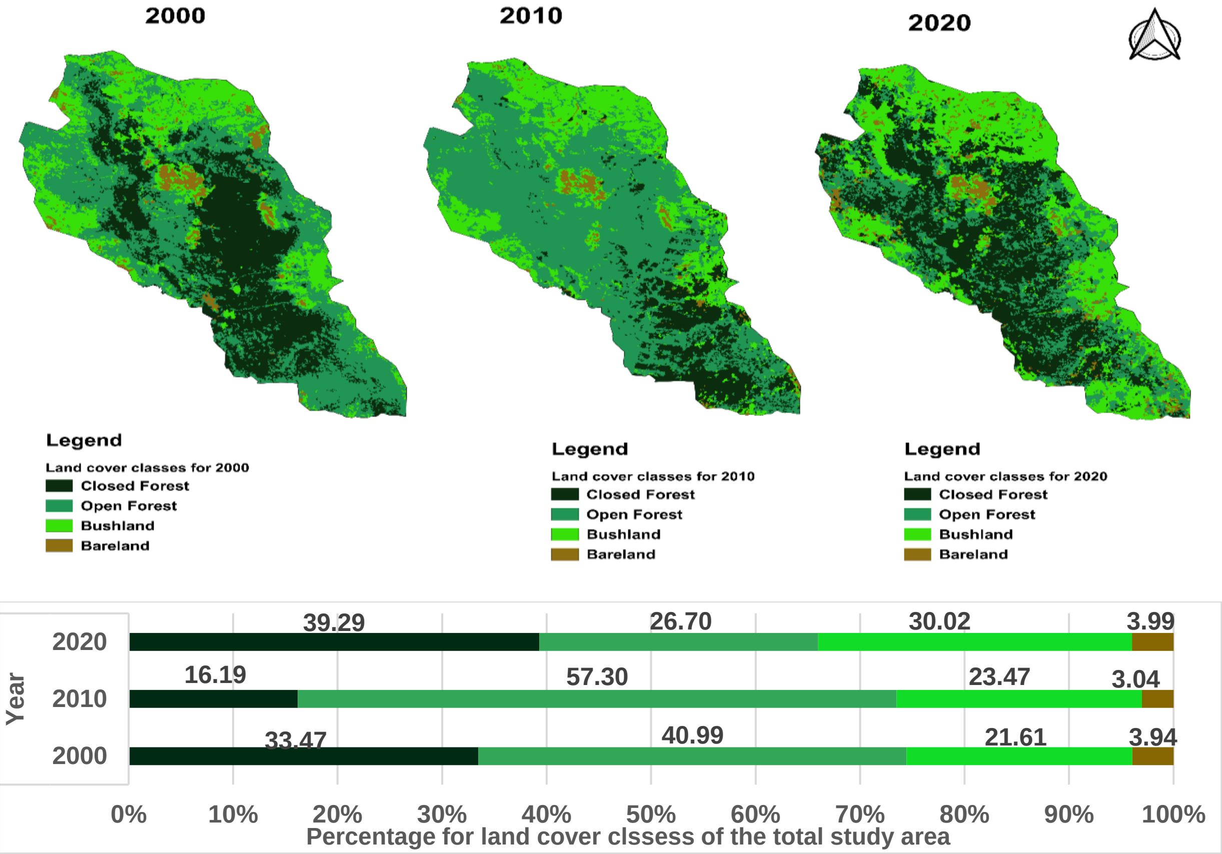

Table 5. Area of Each Land Cover in Ngarama North Forest Reserve 2000, 2010, and 2020

	Area(ha)				
Year	**Closed forest**	**Open forest**	**Bushland**	**Bare land**	**Total**
2000	14,355.63	17,580.41	9,268.366	1,689.29	42,893.7
2010	6,945.17	24,579.74	10,067.26	1,301.52	42,893.7
2020	16,854.00	11,451.61	12,877.12	1,710.96	42,893.7

Rate of Change for Each Land Cover

The analysis of land cover change in the Ngarama North Forest Reserve from 2000 to 2010 reveals significant shifts across various land cover classes, as summarized in Table 6. The closed forest category experienced the most substantial decline, with a total loss of 7,410.5 and a -7.3% annual rate of change. Conversely, the open forest class showed a notable increase, gaining 6,999.3 hectares and a 3.4% annual rate of change. Other land cover classes exhibited varied changes as well. The bushland category increased by 798.9 hectares with an annual rate of change of 0.8%. In contrast, bare land decreased by 387.8 hectares resulting in an annual rate of change of -2.6%. The gains, losses, and net change for each land cover class for 2000–2010 are shown in Figure 4.

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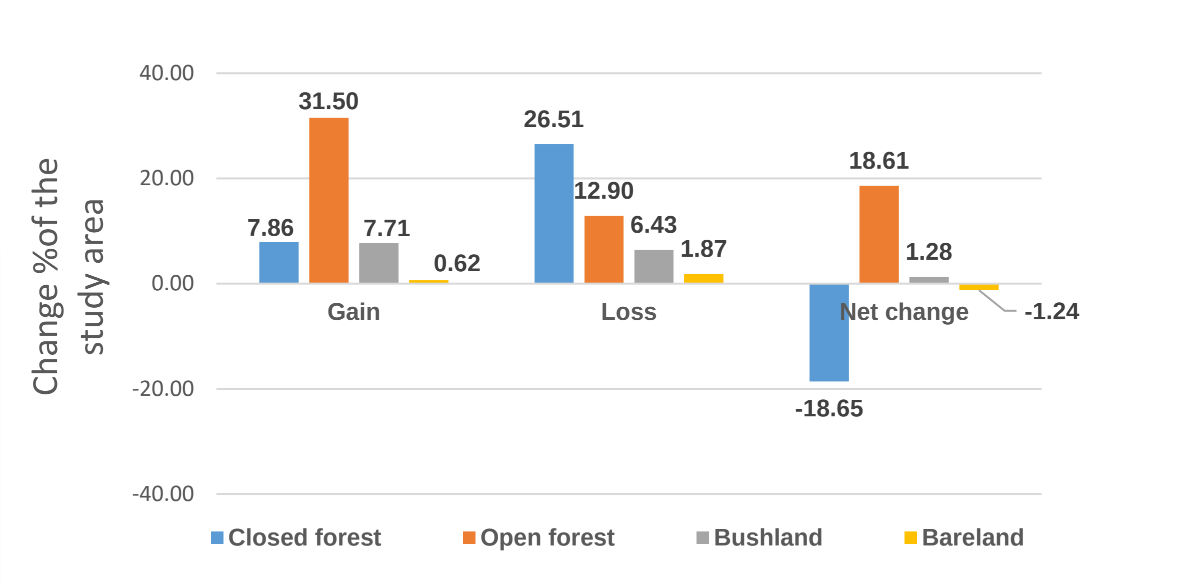
Table 6. Rate of Change for Each Land Cover Class for the Period 2000-2010

Land cover	Total change 2010-2000(ha)	ha/year	2010 area as % of 2000	% annual rate of change
Closed forest	-7,410.5	-741.0	0.5	-7.3
Open forest	6,999.3	699.9	1.4	3.4
Bushland	798.9	79.9	1.1	0.8
Bare land	-387.8	-38.8	0.8	-2.6

Figure 4. Gains, Losses, and Net Change for Each Land Cover Class for the 2000–2010 Period.



From 2010 to 2020, closed forests experienced an increase of 9,908.8 hectares with an annual rate of change of 8.9%. In contrast, open forests witnessed a substantial decline of 13,128.1 hectares, reflecting a decline of 7.6% annually (Table 7). Additionally, bushland increased by 2,809.9 hectares, with an annual rate of change of 2.5%. Bare land recorded a modest increase of 409.4 hectares with an annual rate of change of 2.7%. (Table 7). The gains, losses, and net change for each land cover class for 2010–2020 are indicated in Figure 5.

Table 7. Rate of Change for Each Land Cover Class for the Period 2010-2020 for Ngarama North Forest Reserve.

Land cover	Total change 2020-2010(ha)	ha/year	2020 area as % of 2010	% annual rate of change
Closed forest	9,908.8	990.9	2.4	8.9
Open forest	-13,128.1	-1,312.8	0.5	-7.6
Bushland	2,809.9	281.0	1.3	2.5
Bare land	409.4	40.9	1.3	2.7

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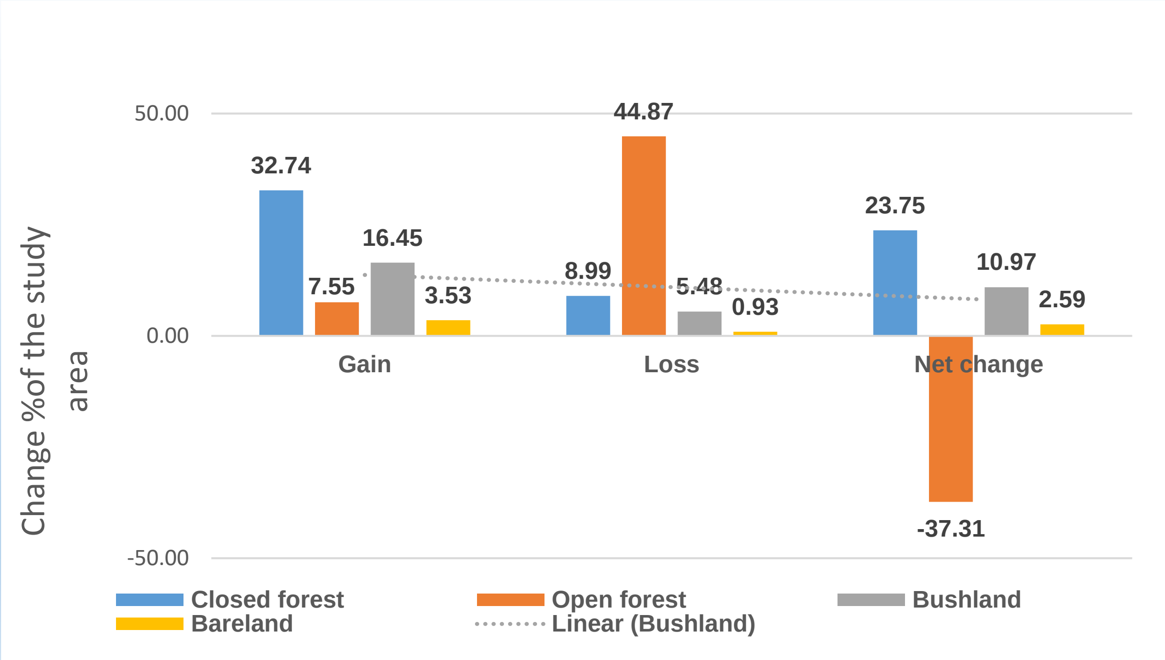
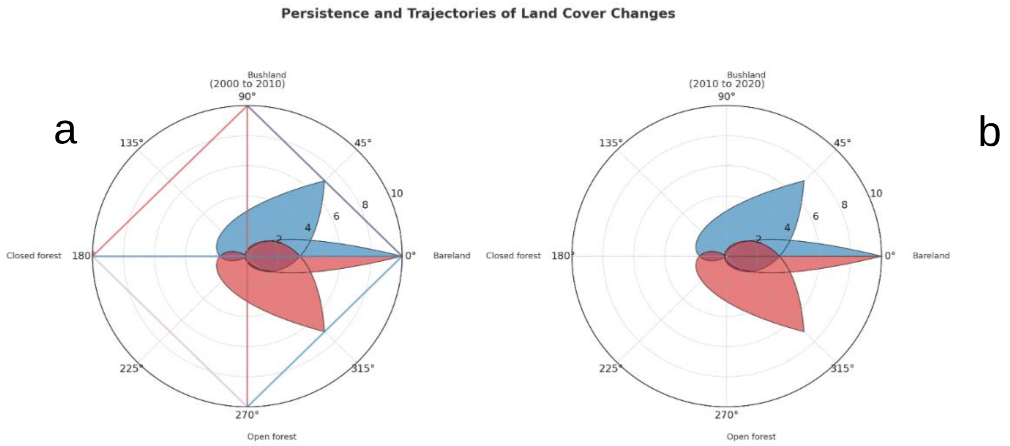
Figure 5. Gains, Losses, and Net Change for Each Land Cover Class for the 2010-2020 Period.



Persistence and Trajectories of Land Cover Changes

Between 2000 and 2010, the largest proportion of open forest was obtained from closed forests followed by bushland and least by bare land. (Figure 6a). Between 2010 and 2020, the largest proportion of open forest changed to closed forest followed by bushland (Figure 6b). In general, the main changes were those of conversion from other land cover types to open forest from 2000 to 2010 while the main changes were those of other land cover to closed forest from 2010-2020 involving more than 30% of the study area (Figure 6a & b).

Figure 6. A Chord Diagram Tracking Trajectories and Persistence of Changes from 2000-2010 and 2010-2020.

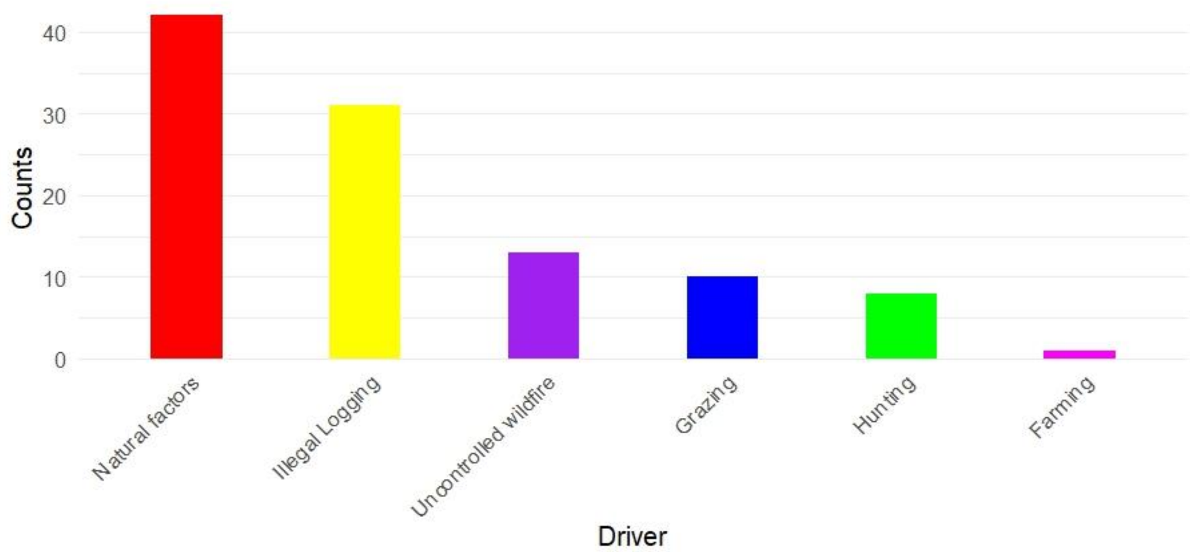


Drivers of Forest Cover Change

Respondents identified several key drivers of forest cover change around and within the Ngarama North Forest Reserve. These included wildfires, grazing, illegal logging, farming, climate change, hunting, mining, honey harvesting, collection of fruits and edible roots and medicinal plants.

Field observations conducted across 170 plots revealed specific instances of some fore-identified drivers impacting forest cover. These are Natural factors which were noted in 42 plots, Illegal logging in 31 plots, uncontrolled wildfire observed in 13 plots, and grazing occurred in 10 plots. Additionally, Hunting was documented in 8 plots, with one plot classified as affected by Farming (Figure 7).

Figure 7. Drivers of Forest Cover Change Encountered Within a Study Area.



DISCUSSION

Forest Cover Change Pattern for the Period 2000 – 2010

The forest cover change patterns observed in this study between 2000 and 2010 reveal a complex interplay of ecological and anthropogenic factors shaping the landscape of Tanzania. The significant decline in closed forest areas coupled with a corresponding increase in open forest areas points to a broader trend of forest degradation and land use transformation. This shift from closed to open forest structures aligns with observations made across various East African landscapes, suggesting a widespread phenomenon of forest ecosystem alteration (Kashaigili et al., 2013; Rotich & Ojwang, 2021). Similar patterns of forest cover change have been observed across different regions, indicating that this issue is not isolated but rather part of a larger environmental crisis affecting various ecosystems globally (Ankomah et al., 2019; Makunga & Misana, 2017).

The marked decrease in closed forest areas aligns with the findings of (Kashaigili et al., 2013), who documented similar declines in closed forests within the Kazimzumbwi and Pugu Forest Reserves between 1980 and 2010. Specifically, the study noted a staggering reduction of closed forests in Kazimzumbwi from 1995 to 2010, suggesting that the trend observed in this study is part of a longer-term pattern of forest degradation. Conversely, the increase in open forest areas reflects findings from (Thonfeld et al., 2020), who identified a similar trend of increasing open woodland at the expense of closed woodland in the Kilombero catchment area from 1974 to 2014. This transition from closed to open forest may indicate a shift in land use practices and ecological conditions, where previously dense forests are being converted into more open habitats due to a combination of factors. These factors are agricultural expansion, illegal logging activities, climate change impacts, wildfires, grazing, encroachment, and institutional failures which have been documented as significant drivers of forest cover change across various landscapes (Andrew, 2022; Bajigo et al., 2020; Doggart, 2023; Fikadu, 2023; Gao et al., 2020; Halofsky et al., 2020; Hosonuma et al., 2012; Kideghesho, 2015; Roberts et al., 2021)

The alarming rate of decline in closed forests poses a serious threat to biodiversity conservation and ecosystem services. Closed forests typically harbour higher species diversity, provide crucial

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habitats for specialized flora and fauna, and play a vital role in carbon sequestration and climate regulation (Hicks et al., 2014; Upadhyay & Singh 2024). The loss of these dense forest structures may lead to cascading effects on local and regional biodiversity, potentially altering species compositions and ecological interactions. Moreover, the shift towards more open forest systems could have significant implications for water cycle regulation, soil conservation, and the livelihoods of forest-dependent communities. These findings underscore the urgency for implementing targeted conservation efforts to halt further degradation of these vital ecosystems through collaborative efforts among stakeholders, including government agencies, local communities, and non-governmental organizations.

Forest Cover Change Pattern for the Period 2010 – 2020

The spatial-temporal analysis of land cover changes in Ngarama North Forest Reserve between 2010 and 2020 reveals a complex ecological transformation that challenges conventional narratives of forest degradation in Tanzania. The significant increase in closed forest areas, coupled with declines in open forest, bushland, and bare land, suggests a dynamic process of forest recovery and densification. This trend contrasts with the broader patterns of forest cover change often reported in East Africa (Aleman et al.,, Jarzyna, and Staver 2017; Alemayehu et al., 2022; Bullock et al., 2021; Jebiwott et al., 2021; Xiao et al., 2022), indicating that localized conservation efforts and natural regeneration processes can yield positive outcomes even in relatively short timeframes.

The observed forest cover changes align with emerging global patterns of forest transition, where some regions experience net forest gains after periods of loss (Muhati et al., 2018; Paudyal et al. 2019; Stritih et al., 2023; Tekalign et al., 2018; Thonfeld et al., 2020). This phenomenon, known as forest transition theory, has been documented in various parts of the world, including some tropical regions (Rudel et al., 2019). The rapid increase in closed forest cover over just a decade suggests that, under favourable conditions, forest ecosystems can demonstrate remarkable resilience and recovery potential (Anderson-teixeira et al., 2013; Camille et al., 2017; Forzieri et al., 2022; Hessburg et al., 2019). Moreover, the observed changes challenge the notion that forest recovery necessarily requires extended periods (Bonnell et al., 2011; Poorter et al., 2021; Wang et al., 2017), as demonstrated by the significant forest densification occurring within a single decade. The increase in closed forest cover supports the argument for sustained or intensified forest conservation policies, reforestation initiatives, and possibly, the promotion of sustainable land use (Karen & Steve, 2018; Nagendra, 2007; Susanna & Timothy, 2014).

The observed pattern contributes significantly to our understanding of forest dynamics in Tanzania and East Africa more broadly. While much of the existing literature focuses on deforestation trends (Doggart et al., 2020; Kashaigili et al., 2013), this study provides a counterpoint, demonstrating the potential for rapid forest recovery under specific management regimes. The findings underscore the importance of site-specific studies in forest conservation, as broad regional trends may not capture localized successes or unique ecological trajectories. Furthermore, this research highlights the need for nuanced approaches to forest monitoring that can capture both losses and gains across different forest types and densities.

These findings have important implications for forest management and conservation policies in Tanzania and beyond. The success in increasing closed forest cover suggests that targeted conservation efforts, possibly combined with reduced anthropogenic pressures, can yield significant positive outcomes for forest ecosystems (Crouzeilles et al., 2016; Drummond et al., 2014; Mammides, 2020). Policymakers and forest managers should consider these results when designing future conservation strategies, potentially focusing on creating conditions that facilitate natural regeneration and forest densification. Additionally, the study underscores

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the value of long-term monitoring and adaptive management approaches in forest conservation, as ecosystem responses to management interventions may manifest over varying timescales. Future research could explore the specific drivers behind the observed forest recovery in Ngarama North Forest Reserve, including the role of policy interventions, community engagement, and natural ecological processes, to inform more effective forest restoration strategies across the region.

Drivers of Forest Cover Changes

The results of our ground-truthing in 170 plots have illuminated critical drivers affecting forest cover, revealing a complex interplay between natural factors and anthropogenic activities. Our observations highlighted the presence of natural factors in a significant portion of the plots, while illegal logging emerged as a substantial threat. Other notable drivers included uncontrolled wildfires, grazing, hunting, and farming, albeit to lesser extents. These findings align with previous research indicating that human-induced pressures, particularly illegal logging and agricultural expansion, are primary contributors to forest degradation in Tanzania (Andrew, 2022; Doggart, 2023). The spatial-temporal analysis further emphasizes that changes from other land cover types to open forest occurred predominantly between 2000 and 2010, while the transition to closed forest was more pronounced from 2010 to 2020. This suggests a dynamic landscape influenced by both natural disturbances and human activities.

Illegal logging and associated activities such as charcoal production and firewood harvesting have been consistently highlighted as major drivers of deforestation in tropical ecosystems (Alban, 2018; Rotich & Ojwang, 2021). Our study corroborates these findings, illustrating that illegal logging not only affects immediate forest cover but also contributes to broader ecological consequences such as shifts in species composition and forest structure. The ongoing challenges posed by these activities are compounded by weak law enforcement and insufficient funding for conservation efforts, as noted by (Manyanda et al., 2021). This systemic failure underscores the need for enhanced governance frameworks that can effectively mitigate the pressures on protected areas.

The impact of uncontrolled wildfires is particularly concerning, as our results indicate that they contributed to the transformation of closed forests into open forests and grass/shrublands over the past two decades. This aligns with (Andrew et al., 2023), who posits that wildfires have significantly altered forest dynamics in the region. The dual threat of climate change exacerbates this issue, leading to unpredictable fire regimes that further complicate management efforts. As climate variability increases, it is crucial to understand the interactions between natural disturbances like wildfire and anthropogenic activities to develop effective conservation strategies.

Moreover, our findings highlight the role of grazing and hunting in forest degradation. While these activities were less prevalent compared to illegal logging, their cumulative effects can lead to significant ecological changes. The presence of grazing and hunting activities observed in some plots suggests that local practices continue to exert pressure on forest ecosystems. This is consistent with earlier studies that emphasize the need for sustainable land-use practices to balance human needs with ecological conservation (Elias et al., 2024). Addressing these issues requires comprehensive community engagement and education to foster alternative livelihoods that reduce reliance on forest resources.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The analysis of forest cover change patterns in Ngarama North Forest Reserve between 2000 and 2020 reveals significant alterations in the landscape over the two-decade period. This study has mapped and quantified the extent of forest cover change, providing crucial insights into the dynamics of deforestation and forest degradation

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within the reserve. The results demonstrate a clear trend of forest loss in the first decade followed by forest gain in the subsequent decade, with closed and open forests experiencing a significant shift over the past 20 years.

The significant forest recovery observed in the later decade highlights the potential of targeted conservation efforts, natural regeneration, and improved management practices to reverse degradation trends. The results show a complex interaction of factors contributes to the observed changes, including but not limited to climate-related stressors, illegal logging, uncontrolled wildfires, grazing, hunting, and farming. By examining these drivers, the research provides valuable context for understanding the underlying causes of deforestation and forest degradation in the area.

The findings from this study emphasize the importance of adopting site-specific strategies and adaptive management approaches to effectively balance ecological conservation with human needs. Furthermore, the study underscores the necessity of robust governance frameworks, community engagement, and sustainable land-use practices to mitigate ongoing pressures and ensure the long-term resilience of forest ecosystems.

Recommendations

Based on the study findings, it is important for the local authorities and conservation organizations to implement targeted interventions so as to address the specific drivers of forest cover change identified in this study. Firstly, stricter enforcement of existing forest protection laws and regulations should be prioritized, particularly in areas experiencing rapid forest cover change. Secondly, Joint Forest Management programs should be established or strengthened to engage local populations in sustainable forest use and conservation efforts. These programs can help to reduce hazardous practices such as illegal logging, forest grazing, hunting, forest fires, and forest encroachment from farming.

Furthermore, it is imperative to engage local communities in sustainable land-use practices and alternative livelihood programs to reduce pressure on forest resources. This can be achieved through education initiatives and the promotion of agroforestry systems that balance human needs with ecological conservation. Additionally, investment in climate change adaptation measures is crucial to mitigate the impacts of climate-related stressors on the forest ecosystem. Developing comprehensive fire management strategies is also essential to mitigate the impact of uncontrolled wildfires on forest ecosystems.

On the other hand, future research should focus on sorting out the specific mechanisms enabling recovery, providing valuable insights for scaling up successful restoration initiatives across Tanzania and beyond.

Finally, continued monitoring and assessment of forest cover change using remote sensing techniques is recommended to track the effectiveness of implemented interventions and inform adaptive management strategies. By addressing these key areas, it is possible to build upon the observed forest recovery and ensure the long-term sustainability of Ngarama North Forest Reserve and similar ecosystems in Tanzania.

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