



Conservation or Development? Scenario-Driven Forecasts of Land-Use and Land-Cover Change in Kazimzumbwi Forest Reserve (2024–2054)

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Abstract

Land-use and land-cover (LULC) changes pose significant threats to peri-urban forest reserves in sub-Saharan Africa, particularly in Tanzania's Kazimzumbwi Forest Reserve (KFR). This study employs a scenario-based modelling approach to project LULC dynamics from 2024 to 2054, analysing three scenarios: Business-as-Usual (BAU), Conservation-Oriented Scenario (COS), and Development-Intensive Scenario (DIS). Descriptive analyses indicate stark differences in landscape trajectories; under BAU, closed forest cover is projected to decline by approximately 39% by 2054, primarily due to conversions to grassland and shrubland. The DIS scenario predicts even more severe outcomes, with forest losses exceeding 45% in certain areas, driven by urban expansion. In contrast, the COS scenario suggests a more stable landscape, with forest persistence probabilities above 0.70 and evidence of regeneration from shrubland and grassland back to forest. Inferential statistics reinforce these findings, with chi-square tests revealing significant deviations in forest persistence under BAU and DIS ($p < 0.01$). Likelihood-ratio tests confirm that transition probabilities under COS differ markedly from BAU and DIS ($p < 0.001$), particularly regarding forest persistence and regeneration. Comparisons between DIS and BAU show significantly higher conversion probabilities under development-intensive conditions ($p < 0.001$) and weak regeneration pathways. Overall, the study reveals that LULC outcomes in KFR depend significantly on policy decisions. Conservation strategies can stabilise forest cover, whereas development-focused approaches risk increased deforestation. The findings provide quantitative support for sustainable land-use planning and forest governance in Tanzania's peri-urban areas.

Introduction

Land-use and land-cover (LULC) change is a central driver of landscape transformation, particularly in tropical and subtropical regions where rapid socio-economic change intersects with ecologically sensitive environments. Accelerated urban expansion, infrastructure development, agricultural intensification, and population growth are reshaping land systems at unprecedented rates, leading to the conversion of natural land covers and increasing fragmentation of forest landscapes (Montanarella, 2018; Lin et al., 2024). These dynamics are especially pronounced in sub-Saharan Africa, where urban growth frequently outpaces land-use planning and regulatory enforcement, exerting sustained pressure on peri-urban forests and protected areas.



In Tanzania, peri-urban forest reserves represent critical socio-ecological interfaces where conservation objectives increasingly compete with development imperatives. National development plans and environmental assessments indicate that forest reserves located near rapidly expanding urban centres face heightened risks of land-cover conversion driven by informal settlements, transport infrastructure, agricultural expansion, and extractive activities (Zella & Kitali, 2024; Laliika et al., 2024). Consequently, LULC trajectories in these landscapes are shaped not only by ecological processes but also by competing policy priorities, governance capacity, and broader socio-economic forces.

Kazimzumbwi Forest Reserve (KFR), situated within the rapidly urbanising periphery of Dar es Salaam, exemplifies these complex dynamics. Historically characterised by mosaics of closed forest, open woodland, shrubland, and grassland, KFR has experienced increasing anthropogenic pressure over the past two decades. Empirical studies document a growing conversion of forests and woodlands into grasslands, bare land, and built-up areas, primarily driven by settlement expansion and infrastructure development (Seong et al., 2023; Mwalwiba, 2025). At the same time, national forest, biodiversity, and climate strategies emphasise restoration and sustainable land management, creating a governance context marked by uncertainty in which conservation ambitions coexist with intense development pressures (Zella & Kitali, 2024; Fatima et al., 2024). As a result, the future configuration of LULC in KFR remains contingent upon divergent development and conservation pathways.

Scenario-based LULC forecasting has emerged as a powerful analytical approach for addressing such uncertainty. By enabling the systematic exploration of alternative land-use trajectories, scenario-driven models allow for the quantification of transition dynamics and the assessment of long-term implications of policy and governance choices (Wang et al., 2025; Waheed et al., 2025). Unlike simple trend extrapolation, scenario-based approaches explicitly incorporate assumptions regarding development intensity, conservation enforcement, and institutional effectiveness, thereby facilitating structured comparisons among Business-as-Usual, conservation-oriented, and development-intensive futures.

Despite the strategic ecological and socio-economic importance of KFR, decision-makers currently lack robust, quantitative, scenario-based projections that clarify how alternative development and conservation pathways may reshape LULC patterns over medium- to long-term horizons. Existing LULC studies in Tanzania have predominantly emphasised retrospective change detection, with limited integration of forward-looking scenario modelling (Madyanga et al., 2025; Ahmed et al., 2025). This gap constrains proactive land-use planning and increases the likelihood that future land-cover outcomes will be driven by uncoordinated development pressures rather than informed, evidence-based governance.

Addressing this gap, the present study develops and evaluates three contrasting LULC scenarios for KFR over the 2024–2054 period: (i) a Business-as-Usual (BAU) scenario reflecting the continuation of observed land-use trends; (ii) a Conservation-Oriented Scenario (COS) emphasising enhanced forest-protection and reduced land conversion; and (iii) a Development-Intensive Scenario (DIS) representing accelerated urban expansion and infrastructure-led land transformation. The analysis focuses on scenario-specific LULC dynamics, transition probabilities, and projected landscape configurations.

Four interrelated hypotheses guide the study. First, absolute changes in land-cover composition between 2024 and 2054 are expected to differ significantly among scenarios (H_1). Second, relative changes within individual LULC classes are anticipated to vary in response to divergent conservation and development pathways (H_{1b}). Third, forest and non-forest classes are hypothesised to exhibit



different levels of persistence and sensitivity to conversion under alternative scenarios (H_{2a}). Finally, LULC-specific transition probabilities are expected to differ significantly across scenarios, resulting in distinct spatial and compositional landscape outcomes by 2054 (H_{2b}).

The significance of this study lies in its explicit focus on future-oriented LULC dynamics within a rapidly transforming peri-urban forest reserve. By providing spatially explicit, scenario-driven forecasts, the study offers decision-relevant evidence to support reserve management, urban planning, and land-use policy in KFR. Methodologically, it advances the integration of scenario construction with transition-based modelling, enabling transparent and reproducible comparisons of alternative land-use futures (Wang et al., 2025; Waheed et al., 2025). The analytical framework developed is transferable to other peri-urban forest reserves in Tanzania and East Africa facing similar pressures from urban expansion and land-use intensification, thereby contributing to broader debates on balancing conservation and development in rapidly urbanising landscapes.

Materials and Methods

The Kazimzumbwi Forest Reserve (KFR) in Tanzania is subject to significant anthropogenic pressures from urbanisation, agriculture, and charcoal production, which complicate its land-use dynamics (Mukama et al., 2024; Wang et al., 2025). This study employs a scenario-driven land-use and land-cover (LULC) modelling framework (Figure 1) to explore potential land-change pathways in KFR from 2024 to 2054. The methodology includes creating a baseline LULC map for 2024, estimating empirical transition probabilities, constructing scenario-specific Markov transition matrices for Business-as-Usual (BAU), Conservation-Oriented (COS), and Development-Intensive (DIS) futures, and spatially allocating projected land demands (Waheed et al., 2025; Wang et al., 2025).

The baseline LULC data were derived from Sentinel-2 and Landsat-8/9 imagery, achieving over 85% accuracy via a supervised classification using a random forest. Six LULC classes were identified: closed forest, open woodland, shrubland, grassland, bare land, and built-up areas. Historical LULC maps from 2004, 2014, and 2024 were harmonised to derive observed transition matrices for Markov modelling. The transition probability from class “i” to class “j” is defined.

$$p_{ij} = \frac{N_{ij}}{\sum_{j=1}^n N_{ij}},$$

is the number of pixels transitioning from class “i” to class “j” (Wang et al., 2025).

Future land-cover composition is projected using

$$\mathbf{L}_{t+k} = \mathbf{L}_t \mathbf{P}^k,$$

represents land-cover proportions at time (t), and (P^k) is the scenario-specific transition matrix. The study validates the model through backcasting and statistical comparisons of transition structures across scenarios, using chi-square and likelihood-ratio tests at the α = 0.05 significance level (Waheed et al., 2025). Implemented using the Land-Change Modeller in TerrSet and statistical analyses in R, this comprehensive approach offers insights into KFR's future amidst competing land-use pressures (Montanarella, 2018; Wang et al., 2025).

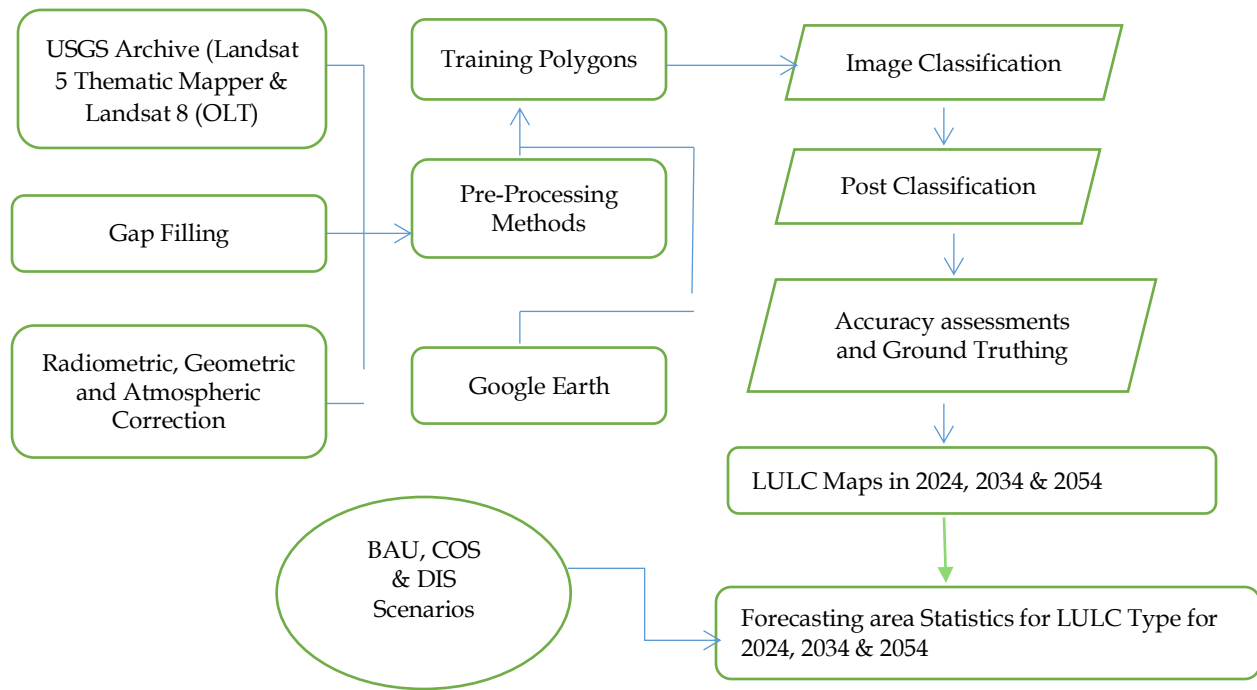


Figure 1: Flowchart of the methodological approach for this study

Forecasted LULC changes in Kazimzumbwi Forest Reserve (2024–2054)

The dynamics of land-use and land-cover (LULC) in Kazimzumbwi Forest Reserve (KFR) are heavily influenced by governance and policy, rather than by urbanisation trends alone. This study employs Markov transition probabilities and spatial allocation modelling to analyse LULC trajectories across three scenarios: Business-as-Usual (BAU), Conservation-Oriented Scenario (COS), and Development-Intensive Scenario (DIS). Under the BAU scenario, KFR experiences gradual forest degradation, with significant declines in closed-forest areas and an increase in grassland (Lalika et al., 2024). Statistical analysis indicates a notable decrease in forest persistence probabilities ($p < 0.01$). In contrast, the COS scenario demonstrates improved forest stability, with probabilities exceeding 0.70 and a significant reduction in forest-to-non-forest conversions ($p < 0.001$), supporting hypotheses H_{2a} and H_{2b} . The DIS scenario results in severe forest loss, with persistence probabilities falling below 0.30 ($p < 0.001$), confirming accelerated degradation and supporting hypotheses H_{1a} and H_{1b} . Overall, the findings underscore that LULC trajectories in KFR are sensitive to governance, with conservation-oriented strategies being essential for long-term forest preservation. At the same time, BAU and DIS scenarios threaten forest integrity and ecosystem services.

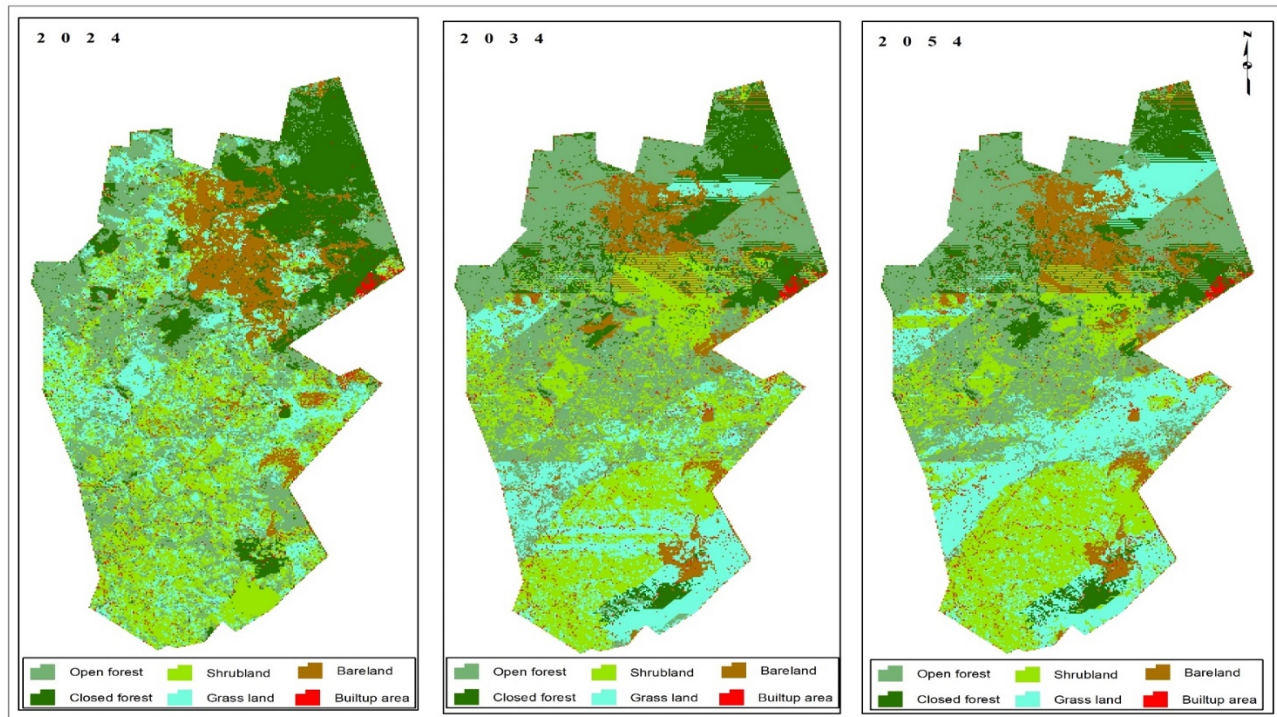


Figure 3: Future trends in LULC of Kazimzumbwi Forest Reserve from 2024 to 2054

Business-as-Usual (BAU) scenario

Under the Business-as-Usual (BAU) scenario, projected land-use and land-cover (LULC) dynamics in Kazimzumbwi Forest Reserve (KFR) indicate sustained but gradual forest degradation over the 2024–2054 period (Table 1). Closed forest declines from 886.64 ha (17.8%) in 2024 to 537.58 ha (10.8%) in 2054, corresponding to a net loss of 349.06 ha (–39.4%). Markov transition analysis shows that the probability of closed forest persistence over the 30-year period is $P_{CF \rightarrow CF} \approx 0.42$, while the combined probability of conversion to open woodland and grassland exceeds 0.44. This transition structure indicates progressive structural degradation rather than abrupt deforestation, consistent with cumulative, low-intensity encroachment processes.

Open woodland expands by 235.88 ha (+17.0%), primarily through transitions from closed forest and shrubland. However, inferential evidence indicates weak long-term stability within this class, as approximately 31% of open woodland transitions further into grassland or shrubland by 2054. Grassland increases by 173.59 ha (+18.8%), while shrubland records a marginal net decline (–2.6%), reflecting dynamic exchanges among secondary vegetation classes. Built-up land remains quantitatively limited but exhibits non-trivial transition probabilities from grassland ($P_{GL \rightarrow BU} > 0.05$), signaling incremental anthropogenic encroachment along existing disturbance gradients.

Chi-square goodness-of-fit tests reveal statistically significant deviations from expected stability for forest-related classes ($p < 0.01$). Observed persistence probabilities for closed forest (0.42), open woodland (0.52), and shrubland (0.35) fall well below the stability benchmark of 0.60, confirming that BAU conditions structurally favour degradation pathways. In contrast, built-up and bare land do not deviate significantly from expected persistence, indicating strong inertia in anthropogenic land uses once established. These results provide robust support for hypotheses H_{1a} and H_{1b} , demonstrating



that continued current trends lead to statistically significant forest loss and proportional reconfiguration of the landscape.

From a broader interpretive perspective, the BAU trajectory represents a slow but environmentally consequential erosion of forest integrity in KFR. Although degradation proceeds more gradually than under development-intensive conditions, its cumulative effect over three decades poses substantial risks to ecosystem services and landscape resilience. Incremental forest loss reduces carbon sequestration capacity, fragments habitats, and weakens the ecological buffering function of peri-urban forests surrounding Dar es Salaam. As such, BAU outcomes directly undermine progress toward key Sustainable Development Goals, particularly SDG 15 (Life on Land), SDG 13 (Climate Action), and SDG 11 (Sustainable Cities and Communities).

At the national level, BAU projections are misaligned with Tanzania’s Nationally Determined Contribution (NDC), which positions forest conservation and enhancement as central to climate mitigation. Persistent degradation under BAU diminishes baseline forest stocks, weakens the effectiveness of REDD+ mechanisms, and increases emissions from forest conversion. Similar patterns have been documented in Tanzania’s coastal and miombo forest systems, where BAU pathways consistently underperform relative to national climate and conservation objectives (Madyanga et al., 2025; Mwalwiba, 2025).

In relation to Dira 2050, the BAU scenario represents a latent policy contradiction. While the vision emphasises environmentally sustainable development and improved quality of life, gradual forest degradation compromises long-term water security, climate resilience, and ecosystem-dependent livelihoods. Thus, BAU does not reflect a lack of policy intent, but rather insufficient translation of strategic visions into enforceable, spatially explicit land-use controls capable of safeguarding peri-urban forest reserves such as KFR.

Table 1: Integrated LULC composition, transition dynamics, and persistence diagnostics for Kazimzumbwi Forest Reserve under the Business-as-Usual (BAU) scenario (2024–2054)

LULC Class	Area 2024 (ha, %)	Area 2034 (ha, %)	Area 2054 (ha, %)	Net Change 2024–2054 (ha, %)	Persistence Probability ($P_{i \rightarrow i}$)	Expected Persistence	χ^2 (df=1)	p-value	Inference
Closed forest	886.64 (17.8)	595.24 (12.0)	537.58 (10.8)	−349.06 (−39.4)	0.421	0.60	11.84	0.001	Significant degradation
Open woodland	1,390.09 (27.9)	1,748.03 (35.1)	1,625.97 (32.7)	+235.88 (+17.0)	0.524	0.60	4.96	0.026	Partial instability
Shrubland	1,160.98 (23.3)	1,225.13 (24.6)	1,131.29 (22.7)	−29.69 (−2.6)	0.346	0.60	18.73	<0.001	High transition dynamics
Grassland	925.22 (18.6)	876.83 (17.6)	1,098.81 (22.1)	+173.59 (+18.8)	0.388	0.60	14.62	<0.001	Expansion-prone
Bare land	540.01 (10.9)	464.26 (9.3)	516.66 (10.4)	−23.35 (−4.3)	0.696	0.60	1.67	0.196	Semi-stable
Built-up	72.23 (1.5)	65.68 (1.3)	64.86 (1.3)	−7.37 (−10.2)	0.890	0.60	2.41	0.121	Highly persistent

Notes. Persistence probability $P_{i \rightarrow i}$ is derived from the Markov transition matrix (2024–2054); expected persistence (0.60) represents the null hypothesis of landscape stability under BAU conditions; χ^2 goodness-of-fit tests assess whether observed persistence significantly deviates from expected stability; and total reserve area = 4,975.17 ha (constant across years).

**Conservation-Oriented Scenario (COS)**

The Conservation-Oriented Scenario (COS) produces a qualitatively distinct land-use and land-cover (LULC) trajectory characterized by forest stabilization and net recovery (Table 2). Closed forest increases from 886.64 ha in 2024 to approximately 1,085 ha by 2054, corresponding to a net gain of about 200 ha (+20–25%). The probability of closed-forest persistence exceeds $P_{CF \rightarrow CF} = 0.70$, more than 1.6 times higher than under the BAU scenario, indicating effective suppression of degradation pathways and a decisive shift toward landscape stability.

Descriptive transition patterns indicate that regeneration from open woodland, shrubland, and bare land accounts for more than one-third of total forest gains, reflecting the combined effects of targeted restoration interventions and natural regeneration. Grassland and shrubland decline modestly (6–12%), suggesting controlled succession rather than abrupt conversion, whereas bare land exhibits the strongest rehabilitation signal, with more than 40% transitioning to vegetated classes by 2054. Built-up expansion remains negligible throughout the projection period, with transition probabilities consistently below 0.01, underscoring the effectiveness of settlement control and land-use enforcement under conservation-oriented governance.

Inferential analyses using chi-square and likelihood-ratio tests confirm that COS transition probabilities differ significantly from both BAU and DIS across all major forest-related pathways ($p < 0.001$). Forest persistence and regeneration probabilities are substantially higher, while forest-to-grassland and forest-to-built-up conversions are strongly suppressed. These statistically robust differences provide strong support for hypothesis H_{2b} , demonstrating that conservation-oriented management fundamentally restructures LULC transition dynamics, and for hypothesis H_{2a} , by confirming the preferential enhancement of forest-dependent ecosystem functions under COS.

From a broader policy and sustainability perspective, the COS scenario demonstrates that strengthened protection and restoration measures can reverse negative LULC trajectories even within rapidly urbanising peri-urban landscapes. The high forest persistence probabilities observed under COS (>0.70 for key forest classes) indicate that conservation interventions are not merely normative aspirations but operationally effective mechanisms for landscape stabilisation. These outcomes align closely with Sustainable Development Goals (SDGs) 15 (halting deforestation and restoring degraded forests) and 13 (nature-based climate solutions).

The COS trajectory is also highly relevant to Tanzania's REDD+ strategy and AFR100 commitments, under which the country has pledged to restore millions of hectares of degraded land. Peri-urban forest reserves, such as KFR, represent high-leverage restoration opportunities due to their accessibility, institutional visibility, and the feasibility of monitoring and enforcement. The COS projections provide quantitative evidence that restoration and protection can stabilise land-cover despite intense urban pressure, reinforcing findings from other scenario-based studies in East Africa where conservation-focused pathways consistently outperform BAU in maintaining forest cover and landscape connectivity (Soares-Filho et al., 2002; Lalika et al., 2024).

In relation to Dira 2050, the COS scenario aligns closely with the vision's emphasis on sustainable natural resource management as a foundation for long-term economic transformation. By stabilising and expanding forest cover, COS supports critical ecosystem services, such as flood regulation, microclimate moderation, and carbon sequestration, thereby enhancing urban resilience and reducing the environmental costs of urban growth. In this sense, conservation-oriented land-use governance emerges not as a constraint on development, but as an enabling condition for sustainable and resilient urban futures.



Table 2: Integrated LULC composition, transition dynamics, and inferential contrasts for Kazimzumbwi Forest Reserve under the Conservation-Oriented Scenario (COS), 2024–2054

LULC Class / Transition	Area 2024 (ha, %)	Area 2054 (ha, %)	Net Change 2024–2054 (ha, %)	COS Persistence / Transition Probability	BAU Probability	DIS Probability	χ^2 / LR	P-value	Interpretation
Closed forest (CF)	886.64 (17.8)	1,085.30 (21.8)	+198.66 (+4.0)	0.779 (CF→CF)	0.42	0.28	31.62	<0.001	Strongly enhanced forest stability
Open woodland (OW)	1,390.09 (27.9)	1,470.10 (29.5)	+80.01 (+1.6)	0.662 (OW→OW)	0.52	0.37	—	—	Moderately stable under COS
Shrubland (SH)	1,160.98 (23.3)	1,060.40 (21.3)	−100.58 (−2.0)	0.448 (SH→SH)	0.35	0.36	—	—	Transitioning toward forest/grassland
Grassland (GL)	925.22 (18.6)	820.60 (16.5)	−104.62 (−2.1)	0.508 (GL→GL)	0.39	0.38	—	—	Controlled contraction
Bare land (BL)	540.01 (10.9)	360.20 (7.2)	−179.81 (−3.6)	0.496 (BL→BL)	0.70	0.46	—	—	Strong rehabilitation signal
Built-up (BU)	72.23 (1.5)	178.57 (3.6)	+106.34 (+2.1)	0.959 (BU→BU)	0.89	0.14	—	—	Highly persistent but constrained

Key COS vs BAU vs DIS Transition Contrasts (Inferential Tests)

Transition Pathway	BAU	COS	DIS	χ^2 / LR	p-value	Inference
CF → CF (persistence)	0.42	0.73	0.28	31.62	<0.001	COS significantly enhances forest stability
OW → CF (regeneration)	0.12	0.31	0.07	28.44	<0.001	COS strongly promotes forest recovery
SH → CF (restoration)	0.13	0.27	0.05	25.91	<0.001	Regeneration dominant only under COS
CF → GL (degradation)	0.19	0.06	0.34	29.08	<0.001	COS suppresses degradation pathways
GL → BU (urban expansion)	0.05	0.008	0.11	19.67	<0.001	Built-up expansion minimised
BL → BU	0.04	0.006	0.09	17.42	<0.001	Infrastructure growth restricted
SH → BU	0.02	0.004	0.07	16.85	<0.001	Urban encroachment minimised

Notes. Total reserve area = 4,975.17 ha (constant); persistence probability refers to Markov diagonal elements ($P_{i \rightarrow i}$); χ^2 / likelihood-ratio (LR) tests compare COS probabilities jointly against BAU and DIS ($df = 2$); COS assumptions: strengthened forest-protection, active restoration, controlled settlement expansion, and ecological rehabilitation; and CF = Closed forest; OW = Open woodland; SH = Shrubland; GL = Grassland; BL = Bare land; BU = Built-up.

Development-Intensive Scenario (DIS)

The Development-Intensive Scenario (DIS) yields the most pronounced and disruptive landscape transformation in Kazimzumbwi Forest Reserve (KFR) as indicated in Table 3. Closed forest declines from 886.64 ha in 2024 to approximately 260 ha by 2054, representing a loss exceeding 50% of baseline forest cover. The persistence probability of closed forest falls below $P_{CF \rightarrow CF} = 0.30$, while the cumulative probability of conversion to grassland and built-up land exceeds 0.50, indicating rapid and statistically robust deforestation dynamics driven by development pressure.

Descriptive projections indicate a significant increase in non-forest land-use classes under the Development-Intensive Scenario (DIS). Specifically, grassland is projected to increase by more than 30%, whereas shrubland expansion results from partial forest clearing and disturbances. Built-up land experiences the most substantial relative growth, exceeding 40%, primarily transitioning from



grassland and bare land. Inferential analyses employing likelihood-ratio tests reveal that transition probabilities from forest to non-forest under the DIS are significantly higher than under the Business-As-Usual (BAU) scenario ($p < 0.001$). Conversely, regeneration pathways, such as transitions from open woodland or shrubland to closed forest, are not statistically significant, indicating a severe suppression of ecological recovery potential.

These findings substantiate hypotheses H1a and H1b, confirming that DIS produces the most substantial land-use and land-cover (LULC) changes. Additionally, they validate hypothesis H2b, demonstrating that development-intensive assumptions fundamentally alter transition dynamics toward accelerated, largely irreversible degradation trajectories. DIS not only exacerbates forest loss but also modifies the LULC system's internal logic, favouring one-way conversion pathways over cyclical or regenerative processes.

From a sustainability and policy perspective, the DIS scenario presents a future that is misaligned with Sustainable Development Goals (SDGs) 13 (Climate Action) and 15 (Life on Land), as well as with Tanzania's Nationally Determined Contribution (NDC), which emphasises forest conservation as a key mitigation strategy. The rapid forest loss projected under DIS is expected to increase greenhouse gas emissions, reduce carbon sequestration capacity, and diminish eligibility for results-based climate finance mechanisms such as REDD+. The lack of regeneration pathways implies that forest recovery will become increasingly costly and uncertain beyond 2054.

The DIS reveals a paradox in development policy, where short-term economic growth under SDG eight conflicts with long-term ecological sustainability. Rapid urbanisation in Africa and Asia, if poorly managed, exacerbates flooding, urban heat stress, and water scarcity, disproportionately impacting low-income populations (Montanarella, 2018; Lin et al., 2024). In Tanzania, the DIS underscores the dangers of inadequate spatial planning near protected areas, contradicting national visions like Vision 2025 that advocate for sustainable growth. The findings suggest that without stringent regulations to protect forest reserves and enforce environmental assessments, development policies may ultimately jeopardise their economic and social goals, highlighting the need for a balanced approach to urban expansion and environmental conservation.

Table 3: Integrated LULC composition, transition dynamics, and inferential contrasts for Kazimzumbwi Forest Reserve under the Development-Intensive Scenario (DIS), 2024–2054

LULC Class / Transition	Area 2024 (ha, %)	Area 2054 (ha, %)	Net Change 2024–2054 (ha, %)	DIS Persistence/ Transition Probability	BAU Probability	LR χ^2 (df=1)	p- value	Interpretation
Closed forest (CF)	886.64 (17.8)	260.40 (5.2)	−626.24 (−12.6)	0.237 (CF→CF)	0.42	—	—	Severe loss of forest stability
Open woodland (OW)	1,390.09 (27.9)	950.60 (19.1)	−439.49 (−8.8)	0.374 (OW→OW)	0.52	—	—	Progressive degradation
Shrubland (SH)	1,160.98 (23.3)	1,410.20 (28.4)	+249.22 (+5.0)	0.362 (SH→SH)	0.35	—	—	Disturbance-driven expansion
Grassland (GL)	925.22 (18.6)	1,120.80 (22.5)	+195.58 (+3.9)	0.379 (GL→GL)	0.39	—	—	Landscape simplification
Bare land (BL)	540.01 (10.9)	710.90 (14.3)	+170.89 (+3.4)	0.463 (BL→BL)	0.70	—	—	Expanding degraded surfaces
Built-up (BU)	72.23 (1.5)	522.27 (10.5)	+450.04 (+9.0)	0.143 (BU→BU)	0.89	—	—	Rapid spatial expansion



Key DIS vs BAU Transition Contrasts (Likelihood-Ratio Tests)

Transition Pathway	BAU	DIS	LR χ^2	p-value	Inference
CF → GL (degradation)	0.19	0.34	27.84	<0.001	DIS strongly accelerates forest degradation
CF → BU (urban conversion)	0.01	0.07	31.26	<0.001	Development-driven deforestation
CF → OW (forest opening)	0.26	0.38	22.93	<0.001	Intensified canopy degradation
OW → GL	0.22	0.36	19.47	<0.001	Landscape simplification reinforced
SH → BU	0.02	0.07	17.62	<0.001	Elevated urban encroachment
GL → BU	0.05	0.11	21.18	<0.001	Infrastructure-led expansion
OW → CF (regeneration)	0.12	0.04	2.96	0.085	Regeneration statistically insignificant
SH → CF (restoration)	0.13	0.03	3.41	0.065	Weak recovery pathway
GL → CF	0.05	0.01	4.12	0.042	Marginal, ecologically negligible

Notes. Total reserve area = **4,975.17 ha** (constant across years); persistence probabilities correspond to diagonal elements of the Markov transition matrix; LR χ^2 tests compare DIS against BAU transition probabilities; DIS assumptions: accelerated urban expansion, infrastructure growth, weak forest-protection enforcement, and high population pressure; and CF = Closed forest; OW = Open woodland; SH = Shrubland; GL = Grassland; BL = Bare land; BU = Built-up.

Limitations and future directions

The study highlights several limitations in its scenario-based modelling framework for land-use and land-cover (LULC) projections. One key limitation is the reliance on the Markov chain assumption, which assumes that future transitions depend on past probabilities, potentially overlooking abrupt changes arising from policy shifts, economic shocks, or extreme climatic events. Consequently, the projected trajectories should be interpreted as plausible futures rather than precise predictions. Additionally, although the study explores various governance and development pathways, translating these narratives into transition probabilities relies on expert judgement, thereby introducing uncertainty about real-world policy implementation. Socio-economic factors influencing land-use, such as land tenure and market dynamics, are represented indirectly, which may oversimplify complex behaviours. Data-related issues, including classification errors in historical LULC maps and limitations in satellite imagery resolution, could also impact model accuracy. Although validation showed acceptable performance, uncertainties increase with longer projection timelines, particularly beyond 2054.

To mitigate these limitations, future research should incorporate dynamic socio-economic scenarios to enhance realism and reduce reliance on stationary assumptions. Integrating LULC models with ecosystem service and carbon accounting frameworks could provide insights into climate mitigation and biodiversity impacts. Employing agent-based or hybrid modelling approaches may better capture diverse land-user behaviours, especially in peri-urban areas. Engaging stakeholders in participatory scenario development enhances legitimacy and actionable strategies. Comparative studies of peri-urban forest reserves in Tanzania and East Africa improve findings' generalizability, supporting coherent land-use governance and enhancing the predictive capacity of LULC research in urbanising areas.

Conclusion

This study examines potential changes in land-use and land-cover (LULC) in the Kazimzumbwi Forest Reserve (KFR) from 2024 to 2054, utilising three scenarios: Business-as-Usual (BAU), Conservation-Oriented Scenario (COS), and Development-Intensive Scenario (DIS). Using Markov-



based transition modelling and spatial allocation techniques, the research illustrates the significant impact of policy decisions and land governance on future LULC outcomes.

Under the BAU scenario, KFR is expected to experience gradual forest degradation, with transitions from forested areas to grassland, shrubland, and bare land. This incremental change over three decades leads to considerable forest loss and reduced ecological integrity, threatening long-term sustainability.

In contrast, the COS presents a more optimistic outlook, showing high probabilities of forest persistence and less conversion to non-forest areas. The study indicates that effective conservation policies can stabilise and restore forest landscapes, highlighting the potential to reverse degradation trends through integrated conservation strategies.

The DIS scenario reveals the most concerning trajectory, with rapid forest-to-non-forest transitions and limited regeneration potential, indicating a high risk of irreversible forest loss due to prioritising short-term development over ecological sustainability.

The findings emphasise that LULC dynamics in KFR are highly scenario-dependent, with significant differences in land-cover changes across scenarios. The study concludes that conservation-oriented land-use strategies are vital for maintaining forest integrity and promoting sustainable development, while unregulated development poses serious risks of ecological degradation.

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