

Sustainability Assessment of Lake Babati Based on Land-Use and Land-Cover Change Patterns and Future Projections

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Abstract - Globally, Land use and land cover changes pose significant threats to the sustainability of reservoirs and lakes particularly in East Africa due to siltation which reduces storage capacity. This study employed the MOLUSCE plugin in QGIS to analyze historical LULC changes from 2016 to 2019 and project future scenarios to 2050 for Lake Babati catchment area. Using Cellular Automata-Artificial Neural Network (CA-ANN) with five driving factors; slope, elevation, distance to road, distance to river and distance to settlement. The model achieved high validation accuracy with Kappa coefficient of 0.99377 and overall accuracy of 99%. Results of projections from 2026 to 2050 revealed continuation of agricultural expansion which increased by 4.53% substantial built-up growth by 0.84% and forest loss by 1.8%. The transition matrix revealed that agriculture as the dominant driver of landscape transformation with 75% of bare land and 15% of forest converted to cropland. Sustainability assessment suggests the catchment is currently moderately sustainable but trending toward unsustainability without intervention. This study provides critical evidence for integrated catchment management and land-use planning to safeguard Lake Babati's ecological integrity.

Keywords: Land Use Land Cover, MOLUSCE, Cellular Automata-Artificial Neural Network, Lake Babati, Sustainability Assessment, Land Use Change Modelling

1. INTRODUCTION

Land use and land cover change constitutes one of the most significant anthropogenic drivers of environmental transformation globally with profound implications for hydrological systems, biodiversity and ecosystem services (Lambin et al., 2003). In East Africa, rapid population growth, agricultural expansion and urbanisation have accelerated landscape modifications particularly which affecting freshwater lake ecosystems that provide essential resources for millions of people (Odhiambo et al., 2020). Lake Babati is a shallow rift valley lake in northern Tanzania, represents these pressures, supporting fishing, irrigation, tourism and biodiversity whereas facing increasing anthropogenic threats.

Recent studies have documented concerning environmental trends in the Lake Babati catchment area. Research by (Katonge, 2018) revealed significant land use changes between 2000 and 2017 with residential and cultivated areas increasing while grazing lands decreased, indicating progressive conversion of natural vegetation. (Okwi et al., 2022) further demonstrated that the lake level is declining at approximately 25 mm (0.025m) per annum. A trend was not fully explained by climatic variability alone which suggesting catchment degradation as a contributing factor. Deforestation and agricultural encroachment in the catchment area have been identified as primary drivers of increased sediments and nutrient loading that threatening water quality and storage capacity. Understanding land use dynamics requires robust modelling approaches that can capture both historical patterns and future courses. The MOLUSCE (Land Use Change Modeler) plugin, integrated within QGIS, provides an accessible yet powerful platform for analysing LULC transitions using Cellular Automata-Artificial Neural Network (CA-ANN) algorithms (Nobrega et al., 2015). This approach combines the spatial capabilities of cellular automata with the learning capacity of artificial neural networks which enabling the identification of driving factors and prediction of future land cover scenarios. Similar applications in East African contexts have successfully simulated land use changes in Lake Victoria catchment (Kundu et al., 2017) and the Kilombero Valley (Heinrich et al., 2021).

The selection of driving factors is critical for accurate LULC modelling. Topographic variables such as slope and elevation influence agricultural suitability and settlement patterns (Msoffe et al., 2011). Closeness to infrastructure including roads and urban centres determines accessibility and development potential (Malek et al., 2019). Distance to rivers affects both agricultural water availability and flood risk while nearness to settlements reflects population pressure and land demand (Lambin et al., 2003). Understanding the relative influence of these factors enables targeted policy interventions for sustainable land management.

The sustainability of Lake Babati depends fundamentally on catchment management practices that maintain hydrological function and ecological integrity. Land use changes that increase surface runoff, sediment delivery and nutrient loading directly impact lake

water quality, storage capacity and aquatic biodiversity (Okwir, 2023). Projecting future scenarios under different management regimes provides decision-makers with evidence for intervention strategies. This study therefore, aimed to analyse historical LULC changes from 2016 to 2019 with the interval of three 3 years which identifying driving factors of landscape transformation, project future scenarios to 2050 and assess implications for Lake Babati sustainability.

2.0 METHODOLOGY

2.1 Study Design

A longitudinal study design was adopted to assess land use and land cover changes in the Lake Babati catchment area from 2016 to 2019 then compared to current LULC of 2026 and finally future projection of LULC patterns to 2050. This design employed the MOLUSCE plugin in QGIS, using Cellular Automata-Artificial Neural Network (CA-ANN) version 5.1.0 with Multi-layer Perceptron algorithm. The model was structured around five LULC classifications which area water body, forest/grassland, barren land, built-up (developed) and agriculture. Three temporal LULC maps of 2016, 2019 and 2026 were used for training, calibration and validation respectively to ensure the model captured historical trends and could be tested against observed data. This design was chosen because it enables both reflective change detection and future scenario modelling using established transition probability matrices.

2.2 Study Area

The study was conducted in the Lake Babati catchment area located within Babati District of Manyara Region, northern Tanzania, at approximately 4°13' South latitude and 35°45' East longitude. The catchment encompasses the lake and its surrounding watershed with elevations ranging from 1,321 to 1,327 metres above mean sea level for the lake basin rising to higher elevations in the surrounding highlands including Mount Kwaraa escarpment. The catchment is characterised by agricultural land, grazing areas, settlements, forested hills and wildlife habitats. The lake has artificial outlet which do not handle effectively inflows which making it highly sensitive to catchment conditions and land use changes that affect runoff, sedimentation and water quality. The spatial domain of the model was defined with dimensions of 852 × 762 cells with 30m resolutions that covered the entire catchment area. The Figure1, show the map of lake Babati catchment area.

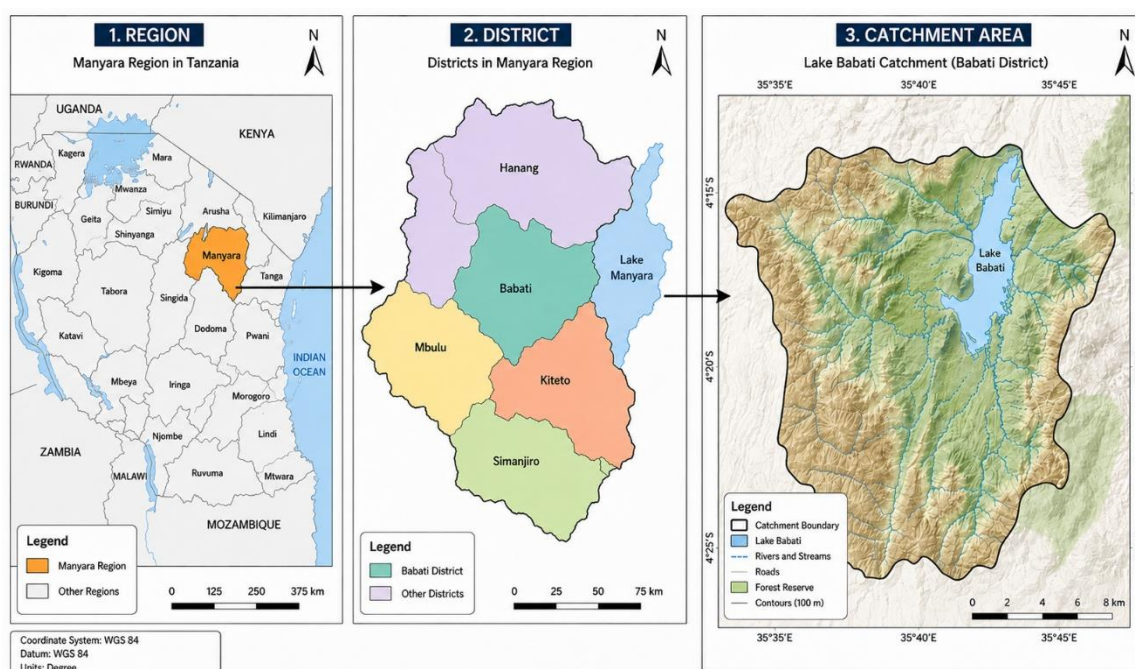


Figure 1: Map of study area

2.3 Data Collection and Preprocessing

Land use and land cover data for 2016, 2019 and 2026 were obtained from classified satellite imagery Landsat 8 OLI/TIRS with consistent spatial extent, cell size (30m resolution), Path of 168 and Row of 063 to ensure compatibility for change detection analysis. Five driving factors were selected as predictors of land use transitions these are slope (derived from DEM), elevation,

distance to road (road map), distance to river (river map) and distance to settlement (urban map). These variables were chosen based on established literature identifying them as major determinants of settlement patterns, agricultural development and environmental change in East African catchments (Msoffe et al., 2011; Malek et al., 2019). All driver layers were pre-processed to match the spatial resolution and extent of the LULC datasets.

2.4 Data Analysis

Pearson Correlation Analysis: Multicollinearity among driving factors was assessed using Pearson's correlation coefficient (r), calculated using the formula:

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

Where X and Y represent two driving factors and $\bar{x}$ and $\bar{y}$ denote their mean values. Correlation coefficients were interpreted as: $|r| < 0.7$ (acceptable), $|r| \geq 0.7$ (potential multicollinearity, consider removing one variable) and $|r| \geq 0.9$ (very strong redundancy, one variable should be excluded). Refer the Table 1 which interpreting the Pearson coefficient.

Table 1: Interpretation of Pearson Correlation Coefficients

S/No	Formula	Description
1	$r < 0.7$	Generally acceptable.
2	$r \geq 0.7$	Potential multicollinearity; consider removing one of the variables.
3	$r \geq 0.9$	Very strong redundancy; usually, one variable should be excluded.

Change Detection and Transition Matrix Analysis: Land cover transitions between 2016 and 2019 were quantified using the change detection technique within MOLUSCE model which calculates the area and percentage of each LULC class and identifies the direction of transformations. A Markov transition matrix was generated to determine the probability of each class either continuing or converting to other classes with diagonal values representing stability and off-diagonal values representing transition probabilities.

Model Calibration and Validation: The CA-ANN model was calibrated using 2016 and 2019 LULC maps with driving factors as predictors. The model then simulated the 2026 LULC map which was validated against the observed 2026 map. Validation revealed the Kappa coefficient of 0.99377 and overall accuracy metrics of 99%. Kappa values were interpreted using the following classification in Table 2.

Table 2: Kappa Coefficient Interpretation

S/No	Kappa Value	Accuracy Level
1	< 0.40	Poor
2	$0.40 - 0.60$	Moderate
3	$0.60 - 0.80$	Good
4	$0.80 - 1.00$	Very Good

Furthermore, the relationship between the Kappa coefficient and overall accuracy were given in Table 3

Table 3: Relationship Between Kappa and Overall Accuracy

S/No	Kappa	Typical Overall Accuracy
1	0.60-0.80	70-90%
2	0.80-0.90	85-95%
3	0.90-0.99	95-99%
4	0.99377	>99%

Future Scenario Projection: Using the validated model LULC conditions were projected from 2026 to 2050 with an interval of three-years adopting the 2019 map as the initial state (baseline map). Projections were based on the transition probabilities derived from historical changes in patterns that assuming continuation of current trends in driving factors.

2.5 Ethical Considerations

The study used publicly available satellite imagery and secondary data sources. There is no primary data collection from human subjects was conducted. The research was conducted under authorisation from the Internal Drainage Basin Water Board (IDBWB) with findings to be shared with relevant stakeholders including district planners, environmental experts, politicians, policy makers, Babati Water Supply and Sanitation Authority (BAWASA) and water user associations to inform sustainable catchment management.

3.0 RESULTS

3.1 Driving Factors Analysis

The evaluation of driving factors revealed that slope, road proximity and urban proximity significantly influenced land use changes within the Lake Babati catchment area. Areas with gentle slopes showed high probability of conversion to agriculture while steep slopes presented low transition probability due to physical limitations. Urban proximity emerged as one of the most effective driving forces with parcels near existing settlements showing high probabilities of transitioning to built-up land use. Road infrastructure similarly enabled land use change by increasing accessibility to economic and other resources.

3.2 Correlation Among Driving Factors

The Pearson correlation coefficients among driving factors were within acceptable limits with no values exceeding $|r| \geq 0.7$ which confirming the absence of significant multicollinearity. This validated the inclusion of all five factors which are slope, elevation, distance to road, distance to river and distance to settlement in the CA-ANN model without redundancy concerns.

3.3 Historical Land Use and Land Cover Changes (2016-2019)

The change detection analysis revealed substantial transformations across the Lake Babati catchment area between 2016 and 2019. Table 4 presents the distribution of LULC classes for both years.

Table 4: Land Use and Land Cover Distribution (2016-2019)

S/No	LULC Class	2016 (km ²)	2019 (km ²)	Change (Δ km ²)	2016 %	2019 %	Change(Δ) (%)	Recommendation
1	Water Body	12.17	12.06	-0.11	3.22%	3.19%	-0.03%	Decreased
2	Built-up	5.613.	11.431	5.818	1.48%	3.02%	1.54%	Increased
3	Bare Land	13.64	9.68.	-3.96	3.61%	2.56%	-1.05%	Decreased
4	Forest	101.86	95.07	-6.79	26.93%	25.13%	-1.80%	Decreased
5	Agriculture	245.00.	257.31	12.31	64.76%	68.02%	3.26%	Increased

Agriculture emerged as the dominant class which expanded from 245.00 km² (64.76%) in 2016 to 257.31km² (68.02%) in 2019 that representing an increase of 12.31 km² (3.26%). This expansion reflects population growth, urbanisation and increasing demand for agricultural production (food).

Forest cover declined from 101.86 km² (26.93%) to 95.07 km² (25.13%) by a reduction of 6.79 km² (1.80%). This deforestation indicates conversion of forested areas to agriculture and settlement driven by land clearing for cultivation, fuelwood and timber harvesting. The environmental consequences include loss of biodiversity, reduced capacity of absorption of carbon and production of oxygen but also accelerated soil erosion due to top cover removed.

Built-up areas increased from 5.613 km² (1.48%) to 11.431 km² (3.02%) with an increment of 5.818 km² (1.54%). This rapid urbanisation reflects population pressure and increasing demand for residential and commercial development particularly around Babati Town.

Bare land decreased from 13.64 km² (3.61%) to 9.68 km² (2.56%) by a reduction of 3.96 km² (1.05%). This decline reflects conversion of bare land to agriculture and built-up areas which was driven by population growth and demand for food production and settlements.

Water bodies experienced a slight reduction from 12.17 km² (3.22%) to 12.06 km² (3.19%) which was decreased by 0.11 km² equivalent to 0.03%. Although this change is minor but this decline indicates ongoing environmental degradation that could impact aquatic life, possibly due to sedimentation, climatic variation or encroachment by agricultural activities in riparian zones which weakening the top soil structure and result into ongoing accumulation of silts in the lake Babati.

3.4 Transition Matrix Analysis

The Markov transition matrix generated by the MOLUSCE model reveals probabilities of each LULC class either persisting or transitioning to other classes between 2016 and 2019 as seen in the Table 5.

Table 5: Transition Matrix Results

Code/	From class	To Class				
		Water	Forest	Agriculture	Built up	Bare land
1	Water body	0.95	0.00	0.05	0.00	0.00
2	Built up	0.00	0.00	0.02	0.98	0.00
3	Bare land	0.01	0.10	0.75	0.05	0.09
4	Forest	0.01	0.80	0.15	0.02	0.02
5	Agriculture	0.00	0.03	0.90	0.05	0.02

The transition matrix shows that agriculture is the dominant driver of landscape changes. High persistence rates were observed for built-up areas by 98%, water bodies by 95%, forests by 80%, agriculture by 90% while bare land showed lower persistence by 9%. Significant transitions from forests by 15% and bare land by 75% to agriculture indicate growing anthropogenic pressure on the catchment area. The probability of water bodies converting to agriculture was 5% while the agriculture converted to built-up by 5%. The result was summarized I the Table 6 clearly.

Table 6: Major Land Cover Transitions to Agriculture

S/No	From Class	To Class	Percentage (%)
1	Forest	Agriculture	15%
2	Bare Land	Agriculture	75%
3	Water Body	Agriculture	5%
4	Agriculture	Built-up	5%

The most significant transitions include bare land to agriculture by 75% which indicating conversion of marginal lands for cultivation. The conversion of forest to agriculture by 15% reflecting deforestation for agricultural expansion. The water body changed to agriculture by 5% that indicating the encroachment into riparian zones and agriculture to built-up by 5% which showing urbanisation of agricultural land.

3.5 Model Learning, Calibration and Validation Performance

The MOLUSCE model was calibrated by using historical LULC maps of 2016 and 2019 togetherness with driving factors then validated by comparing the simulated LULC map of 2026 with the observed LULC map of 2026. The model achieved an overall accuracy of 99% and a Kappa coefficient of 0.99377 that indicated very strong agreement between simulated and actual land use scenarios. The Table 7 justify the model validation results.

Table 7: Model Validation Results

Validation Indicator	Value
Overall Accuracy	99%
Kappa Coefficient	0.99377
Simulation Accuracy	99%

The Artificial Neural Network learning curve demonstrated successful calibration with both training and validation errors decreasing significantly from 0.035 to 0.005 after 100 epochs. The similarity between training and validation curves indicates no overfitting, confirming model stability and reliability for future projections. This was clearly shown in Figure 2.

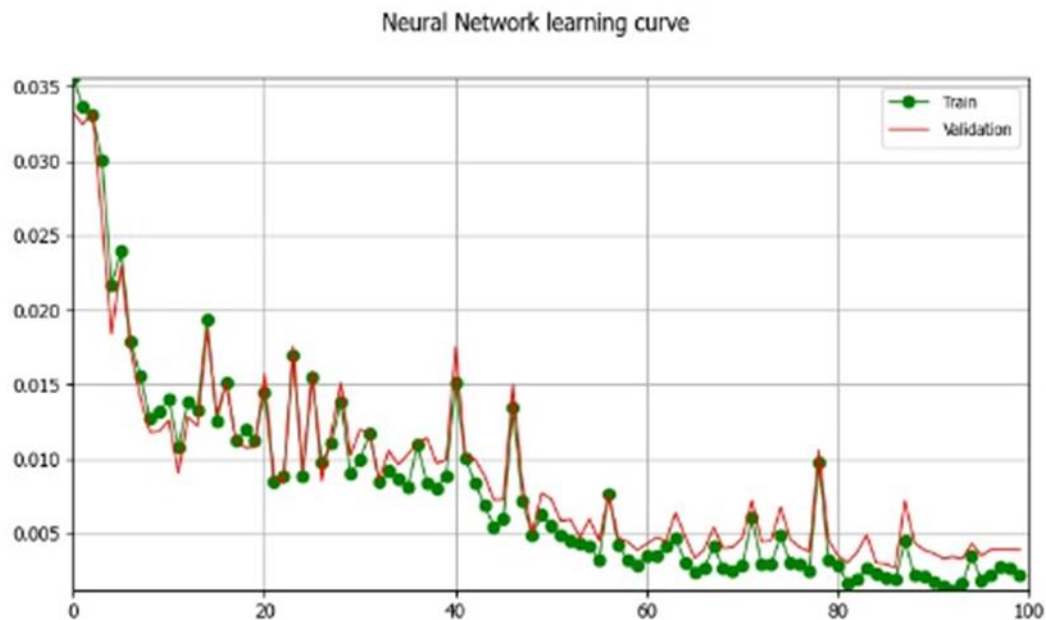


Figure 2: Neural Network learning curve

3.6 Result of Future Land Use Projections from 20226 to 2050

Using the validated CA-ANN model land use conditions were projected from 2026 to 2050. The projections reveal continued landscape transformation across the catchment area resulted from anthropogenic activities within the buffer zones. The Table 8 shows the transition of areas after projection from 2026 to 2050.

Table 8: Projected Land Use Changes from 2026 to 2050

Code	Class	2026 (km ²)	2050 (km ²)	Δ in area	2026%	2050%	Δ%	Recommendation
1	Water	11.91	11.47	-0.44	3.15	3.04	-0.12	Slight decrease
2	Built up	16.74	19.93	3.19	4.43	5.27	0.84	Increase
3	Bare land	9.26	6.32	-2.94	2.45	1.67	-0.78	Decrease
4	Forest	74.59	67.77	-6.82	19.72	17.92	-1.8	Decrease
5	Agriculture	257.64	274.79	17.15	68.11	72.64	4.53	Increase

Agriculture farmland cover is anticipated to increase from 257.64 km² (68.11%) in 2026 to 274.79 km² (72.64%) in 2050. An increase of 17.15km² (4.53 %) is expected. Such considerable increase reflects that farmlands coverage is expected to be on the rising trend due to increase in the population growth and food demand whereas increase in farm's expansion will lead to more vegetative landcover depletion, increased soil erosion and high transport of sediments and nutrients into the Lake Babati. The built-up areas cover is predicted to increase from 16.74 km² (4.43 %) to 19.93km² (5.27%). This represents an increase of 3.19 km² (0.84%). Increased coverage inbuilt area is expected to occur due to an increase of urbanization and constructions in area surrounding the Lake. Although development may have positive impact in economy, the effects could lead to increase in waste generation and water pollution.

The forest area is predicted to decrease by 6.82 km² from 74.59 km² (19.72%) to 67.77 km²(17.92%), a change in land area proportion of 1.80%. Deforestation in the lake catchment area is worrying given the protective roles that forests play in providing habitat for native flora and fauna, regulating the runoff rate in catchment area, mitigating erosion and help in regulation of flow regimes in watercourses in the watershed. Therefore, further losses of forests in the lake catchments are expected to exacerbate the environmental degradation processes within the catchments. On the area of bare land is predicted to decrease from 9.26km² (2.45%) to 6.32 km² (1.67%). This shows a decrease of 2.94km² of land area which is equivalent to loss of 0.78% bare land. This decrease is associated with the change into developed areas, farmlands or cultivation of the barren land as illustrated above in Fig 4.30 This reduction may be accompanied by the removal of the scanty and coarse vegetated cover and disturbance on the loose topsoil.

The water surface is expected to slightly reduce to 11.47km² (3.04%) from the initial 11.91 km² (3.15%), resulting in an estimated loss of 0.44km² equivalent to 0.12%. Despite the relatively small reduction, it reflects the growing stress on the lake ecosystem and may further be attributed to sedimentation accumulation, catchment degradation, water abstraction and changing of weather condition (climate scenarios).

Therefore, land use and land cover change scenario show increase of agricultural land and urban areas at the cost of natural land cover, forests and lakes/water bodies. Agriculture is expected to cover almost 73% of the catchments by 2050 due to increase human population pressure, deforestation and reduction of lakes/water bodies are expected to hamper the ecological services to Lake Babati, leading to risk of soil erosion, sedimentation, loss of soil nutrient, input of nutrients and contaminants to the lake and more and more competition on land and water. All these will reduce resilience of the lake ecosystem over time.

3.7 Sustainability Assessment of Lake Babati

Sustainability analysis based on observed (2026) and projected (2050) conditions identified three potential scenarios for Lake Babati.

Sustainable Scenario: Maintained through effective vegetation cover protection, controlled urban expansion, enforcement of environmental regulations and catchment conservation. This scenario requires monitoring, sustainable land use practices, community participation and protection of riparian buffer zones from encroachment.

Moderately Sustainable Scenario: Achievable with moderate conservation and protection measures, requiring improved catchment management, environmental law enforcement, land restoration and community awareness and fully participation.

Unsustainable Scenario: Results from poor governance, uncontrolled agricultural encroachment, excessive deforestation and urbanisation of buffer zones. This scenario leads to increased water pollution, sedimentation and reduced ecosystem services.

Based on MOLUSCE simulations, Lake Babati currently shows moderate sustainability but is trending toward unsustainability without effective catchment management interventions. The projected land use changes would result in catchment degradation threatening the lake's long-term sustainability.

4. DISCUSSION OF FINDINGS

The findings reveal substantial land use and land cover changes in the Lake Babati catchment area between 2016 and 2019 with projections which indicating continued transformation. The dominant trend is agricultural expansion and urbanisation at the expense of forest and bare land. This pattern aligns with broader regional trends documented across East Africa where population growth and economic development drive conversion of natural vegetation to cropland and settlements (Odhiambo et al., 2020; Lambin et al., 2003).

The 3.26% expansion of agricultural land (12.31 km²) between 2016 and 2019 demonstrates the importance of agriculture as the primary driver of landscape change in the catchment. This expansion is consistent with findings by (Katonge, 2018) who documented increasing cultivation areas surrounding Lake Babati. The conversion of forests which is declined by 1.80% and bare land by 1.05% to agriculture reflects the land demands of a growing population reliant on rain-fed and irrigation agriculture. However, the environmental consequences are significant whereby deforestation reduces absorption of carbon capacity, accelerates soil erosion and diminishes habitat for biodiversity. The 75% transition probability from bare land to agriculture and 15% from

forest to agriculture as revealed by the transition matrix which confirms agriculture as the dominant pathway of landscape transformation.

The 0.84% projected increase in built-up areas by 2050 is concerning. Urbanisation in the catchment area, driven by population growth and economic development, increases impervious surfaces, alters hydrological regimes and contributes to pollution through runoff. The proximity of Babati Town to the lake shore creates particular vulnerability, with urban expansion potentially encroaching into lake buffer zones. This finding aligns with observations by (Okwi et al., 2022) who linked declining lake levels to anthropogenic modifications including spillway expansion and increased abstraction. The 5% transition probability from agriculture to built-up indicates ongoing conversion of agricultural land for residential and commercial development.

The slight reduction in water bodies (0.03% or 0.11 km²) between 2016 and 2019, projected to decline further by 0.12% by 2050, raises concerns about lake sustainability. Although the historical decline appears minor but it is a signal of ongoing environmental degradation. Factors contributing to lake reduction include catchment degradation, sedimentation and encroachment into riparian zones. The 5% transition probability from water body to agriculture revealed by the transition matrix suggests direct encroachment into lake margins. (Okwir, 2023.) confirmed hydraulic connections between Lake Babati and surrounding aquifers, meaning land use changes that affect groundwater recharge directly impact lake levels. The projected 1.8% decline in forest cover by 2050 would exacerbate this by reducing infiltration and increasing surface runoff.

The high model validation overall accuracy of 99% and Kappa coefficient of 0.99377 confirms the reliability of the MOLUSCE model for this study. This performance compares favourably with other LULC modelling studies in East Africa (Kundu et al., 2017) achieved Kappa values from 0.85-0.95 for Lake Victoria catchment studies while (Heinrich et al., 2021) reported 0.82-0.92 for Kilombero Valley. The superior performance observed here may reflect the relatively short temporal interval (3 years) and the dominant trend of agricultural expansion which simplifies the transition patterns captured by the model. The ANN learning curve showing reduction in both training and validation errors to 0.005 after 100 epochs which indicates successful learning without overfitting.

The driving factors analysis identified slope, road proximity and urban proximity as significant determinants of land use change consistent with established literature. Gentle slopes were preferentially converted to agriculture, reflecting physical suitability for cultivation. Roads and urban centres facilitated land use change by increasing accessibility confirming findings by (Malek et al., 2019) regarding infrastructure-driven landscape transformation. The absence of significant multicollinearity (Pearson $r < 0.7$) validates the inclusion of all five drivers in the model. This suggests that each factor contributes unique explanatory power with topography, proximity to infrastructure and proximity to settlements representing distinct but complementary drivers of change.

The sustainability assessment highlights three possible trajectories for Lake Babati. The catchment currently exhibits moderate sustainability with agricultural expansion driving landscape transformation while forest cover declined but still provides some ecosystem services. However, the projections indicate movement toward unsustainability if current trends continue without intervention. The 2050 scenario of 1.8% forest loss and 0.84% built-up increase would substantially alter hydrological function, reduce water quality and degrade habitats. This aligns with (Plisnier et al., 2013) who demonstrated that East African lakes are highly sensitive to catchment changes with small worries capable of driving major ecological shifts.

The implications for water resources are significant. Forest loss reduces infiltration capacity, increasing surface runoff and erosion while agricultural expansion increases sediment delivery and nutrient loading (Lyon et al., 2016). The projected 0.12% reduction in water body area by 2050 would reduce lake storage capacity compounding the 49.50 MCM capacity established by the bathymetric survey. Sedimentation already identified as a concern in the catchment area would accelerate with continued deforestation and agricultural expansion on steep slopes.

From a policy perspective, the findings underscore the urgency of integrated catchment management. The transition matrix identifies agriculture as the dominant driver of forest conversion, suggesting that interventions targeting agricultural practices could yield significant conservation benefits. Agroforestry, conservation agriculture and protection of riparian buffer zones could reduce the rate of forest loss while maintaining agricultural productivity. The high persistence of water bodies by 95% indicates that the lake retains ecological integrity but the 5% transition probability to agriculture suggests vulnerability to encroachment which requiring protection of lake buffer zones.

The limitations of the study should be acknowledged. The MOLUSCE model relies on historical trends which limiting its ability to incorporate sudden policy changes, climate variability or economic shocks. Water quality parameters, sedimentation processes and biodiversity indicators were not included due to data constraints. Future research should integrate climate change scenarios, combine MOLUSCE outputs with hydrological models, and incorporate socioeconomic drivers of land use change to provide comprehensive sustainability assessment.

5. CONCLUSION AND RECOMMENDATIONS

This study successfully applied the MOLUSCE model to analyze historical land use and land cover changes from 2016 to 2019 and project future scenarios from current LULC of 2026 to 2050 for the Lake Babati catchment. The CA-ANN model achieved very high validation accuracy with Kappa coefficient of 0.99377 and overall accuracy of 99% which confirming its reliability for predictive modelling. Projections findings to 2050 revealed continued agricultural growth by 4.53%, substantial built-up expansion by 0.84% while forest loss by 1.8%. The transition matrix identifies agriculture as the dominant driver of landscape transformation with 75% of bare land and 15% of forest converting to cropland. Sustainability assessment suggests the catchment is currently moderately sustainable but trending toward unsustainability without intervention. These findings provide critical evidence for integrated catchment management and land-use planning to safeguard Lake Babati's ecological integrity.

Based on these findings the following recommendations are proposed:

Catchment Area Conservation: Strengthen protection programs for catchment areas, particularly riparian buffer zones around Lake Babati. Enforce prohibition of encroachment into lake margins and implement integrated catchment area management practices. The 5% transition probability from water body to agriculture indicates vulnerability requiring immediate intervention.

Sustainable Agriculture: Promote conservation agriculture and agroforestry practices to reduce deforestation while maintaining agricultural productivity. Prohibit cultivation within lake buffer zones and implement terracing and soil conservation measures on erodible slopes to reduce sedimentation.

Afforestation and Reforestation: Implement immediate measures to restore degraded catchment areas through community-based tree planting initiatives within buffer zones and forest conservation. The projected 1.8% forest loss by 2050 requires urgent restoration efforts to maintain ecosystem services.

Land Use Planning: Develop and enforce environmental land-use plans and regulations to control settlement expansion. The projected 0.84% increase in built-up areas requires proper spatial planning to prevent encroachment into sensitive catchment zones.

Monitoring and Evaluation: Establish systematic monitoring of sedimentation, water quality, and encroachment of buffer zones using remote sensing. Update LULC maps every five to ten years to track changes and inform adaptive management.

Future Research: Integrate climate change scenarios into land-use simulations to assess climate-land use interactions. Assess water quality dynamics alongside land cover changes to evaluate pollution impacts. Quantify sedimentation impacts on lake storage capacity based on established bathymetric baselines. Investigate socioeconomic drivers of land use change to understand underlying causes. Combine MOLUSCE outputs with hydrological models for comprehensive sustainability assessment of Lake Babati.

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