Spatiotemporal Analysis and Forecasting Model in Tropical River Basin for Sustainability Land Management

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Spatiotemporal Analysis and Forecasting Model in Tropical River Basin for Sustainability Land Management

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Abstract: *Land use and land cover (LULC) changes significantly impact environmental sustainability and ecosystem. This study analyzes the LULC in the Nenggiri River Basin, Malaysia as one of tropical river basin for five selected years 2005 - 2024 while forecasts change for 2040 using the GIS and CA-Markov model. Landsat imagery obtained from USGS was processed in ArcGIS software for classification, and future projections produced using TerrSet software. The findings indicate that between 2005 and 2024, there a significant decrease in forest cover from 97.29% to 80.35%. Meanwhile, agricultural land increased from 0.19% to 3.16%, and open areas expanded from 2.25% to 15.23%. Projections for 2040 indicate further forest loss to 60.05%, with agriculture and open areas rising to 4.80% and 32.77%, respectively. These changes highlight major ecological risks if current trends continue. Effective land management strategies are urgently required to reduce environmental deterioration and promote sustainable development in indigenous community.*

Keywords: Land Use Land Cover, Forest Degradation, Environmental Sustainability, Indigenous Communities

1. INTRODUCTION

Over the past decades, human causes of changes in land use land cover (LULC) affected ecosystems globally. These changes have an impact on important environmental processes, such as the geographic distribution of biodiversity, hydrological cycles, and carbon storage [1]. As emphasized by [2], changes in land use and land cover (LULC), also have a direct impact on ecosystem health, water resources, and biodiversity, as it's an important indicator of human-environment interactions. Rapid changes in land cover, including deforestation, agricultural growth, and settlement expansion, can cause irreversible environmental degradation and are frequently driven by socioeconomic development [3,4]. Monitoring and forecasting these changes is critical for developing sustainable land use regulations, particularly in environmentally sensitive areas [5,6].

In Malaysia, such land use changes are becoming more visible in ecologically sensitive areas such as the Nenggiri River Basin in Kelantan state. This basin serves as an important watershed and is home to the Temiar indigenous community, whose traditional ways of life depend significantly on forest resources and the health of the surrounding ecosystem. Over the last two decades, this area has been under increasing pressure from infrastructure projects, commercial agriculture, and timber exploitation, resulting in the habitat disruptions and primary forest loss. These pressures put the basin's natural stability as well as the traditional sustainability of indigenous livelihoods under risks. Thus, it is essential to comprehend land use land cover trends in order to promote inclusive and environmentally friendly planning.

This study takes a geographical approach to analyzing LULC evolution, employing Landsat satellite images processed in ArcGIS and focuses on five critical years likely 2005, 2010, 2015, 2020, and 2024.TerrSet software simulated future land cover possibilities for 2040 using the CA-Markov model, which combines Markov Chain transition probabilities with Cellular Automata to model spatial dynamics. The model projects spatial patterns based on probabilistic trends by utilizing past land cover transitions [7]. This approach gives more detailed information about possible environmental paths and human implications by capturing the severity and geographical pattern of land transitions.

The findings of this study contribute to significant global frameworks, particularly the United Nations Sustainable Development Goals (SDGs). The study directly addresses SDG 13 (Climate Action) by identifying land-use drivers that contribute to climate vulnerability, as well as SDG 15 (Life on Land) by measuring forest loss and its ecological consequences. The results offer vital insights for striking a balance between land development and conservation on indigenous lands. Through utilizing geospatial technologies to understand LULC trends, local and national authorities can better prepare for a more resilient and sustainable future while also reducing environmental concerns.

2. MATERIALS AND METHODOLOGY

2.1 Study Area

This study was carried out in Nenggiri river basin, located in the Gua Musang, a state of Kelantan, Malaysia. This basin has ecological significance and is home to indigenous Temiar villages in addition to a variety of flora and fauna. The Nenggiri River Basin was home to approximately 15,000 Temiar tribe indigenous people who, among other things, relied on traditional farming, fishing, and hunting methods. The areas were a perfect subject for examining land use dynamics because of the growing strain on land development such as agricultural expansion and urbanization. It is in an area with a tropical rainforest environment, which supports deep forest cover and receives a lot of rainfall each year. This study combined spatial modeling approaches with remote sensing data to assess land use trends in the past and future. The method includes gathering data, classifying images, and forecasting with the CA-Markov model. Figure 1 display the location of study area.

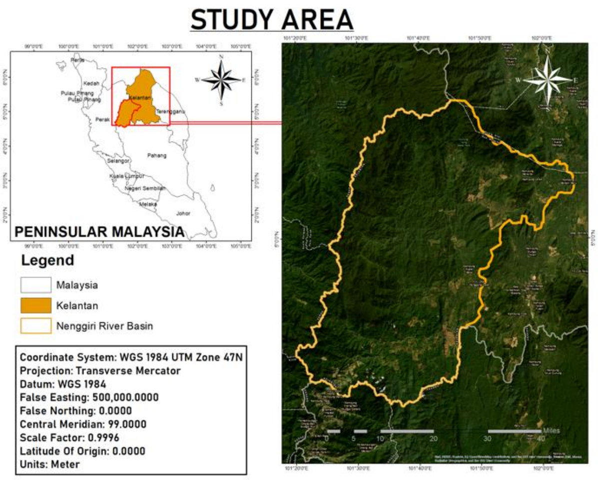

Fig 1. The study area, Nenggiri River Basin.

2.2 Data Collection

The United States Geological Survey (USGS) Earth Explorer platform provided five sets of Landsat satellite imagery for the following years, 2005, 2010, 2015, 2020, and 2024. Every imagery was selected with a spatial resolution of 30 meters and minimal cloud cover. Based on each year's availability, the dataset contained imagery from Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI. Table 1 shown the satellite information from USGS. Ancillary data such cadastral boundaries, topographic maps, and high-resolution images from Google Earth were included to help classification and increase accuracy, especially for ground-truthing and training sample verification [8]. Forest, agriculture, open area (which includes built-up areas and bare ground), and water are the four main groups of land use that the study identified and categorized using a supervised classification approach. The primary land cover categories in the Nenggiri River Basin that are relevant to both ecological processes and human activity were reflected in this classification scheme.

Table 1. Satellite information from USGS

Sensor	Spatial Resolution	Date Acquisition
Landsat 5 LT05	30 m	19/06/2005
Landsat 5 LT05	30 m	26/12/2010
Landsat 8 LC08	30 m	15/08/2015
Landsat 7 LC08	30 m	09/04/2020
Landsat 8 LC08	30 m	27/06/2024

2.3 Image Processing and Classification

ArcGIS software version 10.7.1, an established geographic information system (GIS) platform for remote sensing analysis, was used for image preprocessing and classification. Preprocessing steps includes atmospheric correction, subsetting, and band stacking were prepared. For the multi-temporal Landsat imagery to be consistent geometrically and radiometrically, these steps were essential [9]. Land use land cover (LULC) maps were created by supervised classification using the Maximum Likelihood Classification (MLC) algorithm, recognized for its ability to handle class separability and spectral variability. LULC maps offer useful data for a number of uses, such as land use change analysis, urban planning, environmental monitoring, and natural resource management [10]. The selection of training samples for the forest, agriculture, open area, and water classes were based on visual interpretation, past knowledge, and high-resolution Google Earth references. The reliability and validity of the classification results were ensured by conducting a post-classification accuracy assessment utilizing error matrices and the Kappa coefficient, which measure the agreement between classed output and reference data [11].

2.4 Forecasting LULC Using CA-Markov

The TerrSet 2020 software's a comprehensive geospatial modeling program created by Clark Labs, was used to execute the Cellular Automata–Markov (CA-Markov) model for land use and land cover (LULC) forecasting. The model's Markov Chain component examined past LULC maps to produce transition probability matrices, which measure the chance that each land category would eventually change into another [12]. Cellular Automata (CA) simulate the propagation of land cover changes across a landscape while taking into account neighborhood impacts and spatial proximity [13]. To enhance the spatial realism of the projections, transition potential maps and suitability maps were made utilizing historical drivers of change and proximity variables as the distance to highways, rivers, and communities. Through creating spatially detailed LULC maps for 2040, the integrated CA-Markov model provided information on the probable land cover configuration in the event that current trends continue. This method offers a trustworthy framework for evaluating how land change affects ecosystem health and developing intervention plans that support sustainable development goals.

3. RESULTS AND DISCUSIONS

This section provides the results of the land use and land cover (LULC) analysis for the Nenggiri River Basin during five key observation years 2005, 2010, 2015, 2020, and 2024 as well as future estimates for years 2040 based on the CA-Markov modeling approach. This study identified important trends and changes in land categories through spatial and temporal examination, paying special attention to the emergence of open spaces, agricultural growth, and forest degradation. These trends of changes show the necessity of sustainable land management to preserve the region's biological integrity and indigenous livelihoods, as well as to reflect continuous anthropogenic pressures.

3.1 Accuracy Assessment

For each of the following time periods, accuracy tests were carried out to guarantee the accuracy of the classified land use and land cover (LULC) maps for 2005, 2010, 2015, 2020, and 2024. Producer's accuracy, user's accuracy, overall accuracy, and the Kappa coefficient were among the accuracy metrics, which are all common measurements in the validation of remote sensing categorization. Table 2 display the accuracy assessment for Kappa coefficient. The Kappa statistics (Kstat) values were both 0.78 for the years 2010 and 2020, while the results for 2005, 2015, and 2024 were 0.83, 0.82, and 0.89 respectively. A kappa score of 0.8 or above indicates significant agreement, whereas a value between 0.61 to 0.8 indicates very strong agreement [14]. Thorough pre-processing, choosing high-quality Landsat imagery with little cloud cover, and using the Maximum Likelihood Algorithm for supervised classification are all factors that contribute to the high classification accuracy. These accuracy evaluations offer assurance regarding the LULC change analysis that follows, and the predicted results obtained from the CA-Markov model.

Table 2. Accuracy assessment for Kappa Coefficient

LULC Class	2005		2010		2015		2020		2024	
	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA
Forest	87.5	87.5	87.5	75	100	75	87.5	87.5	88.9	100
Open Area	87.5	87.5	88.9	100	100	100	87.5	87.5	100	100
Agriculture	88.9	100	87.5	87.5	72.7	100	87.5	87.5	87.5	87.5
Cropland	100	83.3	100	83.3	100	83.3	83.3	83.3	100	83.3
Overall Accuracy (OA)	90		86.7		90		86.7		93.3	
Kappa statistics (K_{stat})	0.83		0.78		0.82		0.78		0.89	

*0.8 or above : significant agreement,
0.61 - 0.8 :very strong agreement
Source : [14]

3.2 Land Use Land Cover Changes (2005 - 2024)

The examination of satellite-derived LULC data shows significant ecological transformation throughout the 19-year period. In 2005, the Nenggiri River Basin remained primarily unaltered, with forest cover dominating 97.29% of the region. Agricultural land accounted for only 0.19%, open area was minor at 2.25% and water bodies represented only 0.27%, reflecting natural river systems. The minimal level of human disturbance is consistent with a period before significant commercial encroachments or infrastructure projects had become more prevalent in the area.

By 2010, the percentage of forest area had decreased to 93.26%, while open area had increased considerably to 5.29%. Additionally, the percentage of agricultural land rose to 1.13%, showing the beginnings of land transformation. This change correlates with the basin's initial stages of road construction and logging concessions. The degradation of forest areas threaten biodiversity [15], while increase in agricultural activities indicate shifting from traditional farming to intensive cultivation-industrial farming [16].

The period between 2010 and 2015 experienced only minor changes, although the spatial pattern of disruption became more concentrated. In 2015, forest cover decreased marginally to 92.46% but open area increased to 5.95%. Agricultural land shown increment to 1.22%. Significantly, a large number of these land conversions took place close to logging routes and riverbanks, which increased the dangers of sediment runoff and edge impacts into the Nenggiri River system. Increases in open area with 5.95% are frequently linked to pre-development operations like post-logging abandonment or land preparation. Additionally, water bodies expanded marginally to 0.37%, either as a result of artificial ponding in cleared areas or the growth of surface runoff.

During 2020, the transition became clearer, indicating the beginning of rapid land use changes. More notably, the forest area decreased to 89.12%, while the open area increased to 8.80%. Either the introduction of additional farmland or the intensification of existing plots is what caused the increase in agricultural land to reach 1.61%. These shifts are probably related to more general land use changes from subsistence to commercial or cash-crop farming, which may be brought on by outside investment or development pressures. Policy-driven land allocation for public infrastructure or industrial usage may also be shown in this period, reflecting the growing conflict between economic growth and environmental preservation.

LULC changes become more noticeable by 2024. The percentage of forest cover decrease further to 80.35%, indicating drop of 9% from 2020 with total loss of almost 17% from 2005. The extent of open area rose significantly to 15.23%, more than doubling from 2020, most likely as a result of early-stage development projects, logging roads, and increasing land clearing, including the agricultural activities and urbanization development. The expansion of agricultural land to 3.16% reflects continued cultivation and agricultural projects. The increase in water to 1.26% might be a result of landscape hydrological changes, such as dammed areas or widened riverine zones brought on by sediment displacement. Figure 2 present the percentage of land use land cover (LULC) for 2005 - 2024. While table 3 shown the areas percentage of LULC coverage type and figure 3 display the LULC of Nenggiri River Basin.

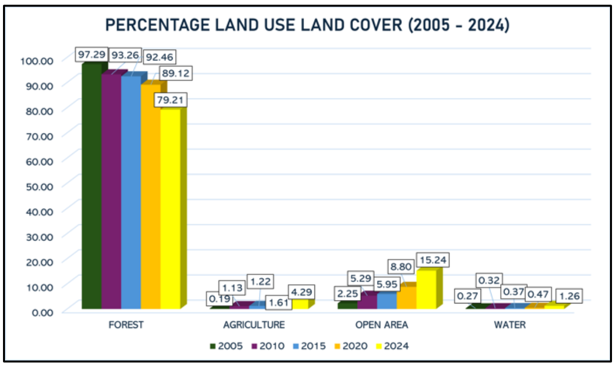

Fig 2. The percentage land use land cover (LULC) 2005 - 2024

Table 2. Areas and percentage of LULC coverage type

	2005		2010		2015		2020		2024	
Type of Coverage	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Forest	3885.51	97.29	3724.89	93.26	3692.6	92.46	3559.37	89.12	3205.90	80.35
Agriculture	7.78	0.19	45.03	1.13	48.6	1.22	64.23	1.61	125.94	3.16
Open Area	89.78	2.25	211.11	5.29	237.78	5.95	351.52	8.80	607.8	15.23
Water	10.84	0.27	12.88	0.32	14.91	0.37	18.74	0.47	50.4	1.26

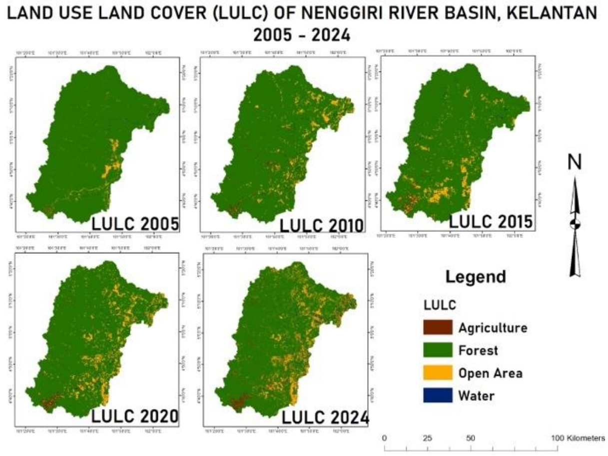

Fig 3. LULC of Nenggiri river basin

3.3 Forecasted Land Cover for 2040.

The Nenggiri River Basin's land cover estimates for 2040 show a persistent pattern of ecological change based on the CA-Markov modeling done in TerrSet software. Forest cover is predicted to drop to 60.05% if current land use practices remain uncontrolled, which would be a 37.24% decrease from the initial baseline (97.29%) in 2005. The estimated loss demonstrates the substantial loss of forest ecosystems, which have traditionally given the indigenous Temiar communities vital environmental benefits and cultural significance.

Concurrently, it is anticipated that open area will increase from 2.25% in 2005 to 32.77% in 2040. Increased infrastructural development, increased land clearing, and possible surface deterioration are all factors in this rapid increase. With agricultural land expected to reach 4.80%, agriculture operations are expected to develop modestly but steadily, perhaps for both commercial and subsistence reasons. An estimated 2.38% of the basin will be covered by water bodies, indicating possible changes in hydrological features brought on by reservoir construction, river damming, or changed surface runoff dynamics brought on by deforestation. Figure 4 demonstrate the projected land use land cover for 2024.

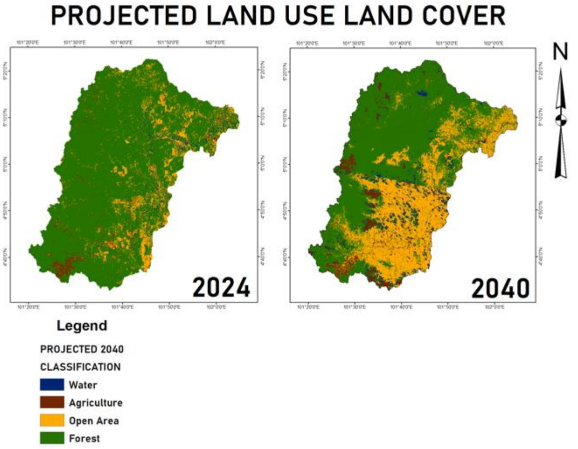

Fig 4. Projected (forecasted) land use land cover (LULC) for 2040.

The probabilistic transitions used to generate these forecasts are based on the observed changes in land cover from 2005 to 2024. High-risk areas for land conversion are those that are close to roads, rivers, and populated areas, especially those with mild terrain. The Cellular Automata integration provides geographical context by capturing clustering effects and neighborhood influence, whereas Markov Chains estimate transition likelihoods using historical patterns.

These expected changes will have severe environmental implications. As stated by [17], the loss of forest cover is expected to decrease soil infiltration capacity, increase surface runoff, and accelerate regional warming. This could lead to increased nutrient loading, sedimentation of rivers, and a decrease in water quality as well as more frequent flooding events. Furthermore, the growth of agricultural and open spaces can disrupt regional hydrological cycles, fragment important wildlife habitats, and increase carbon emissions by reducing biomass [18]. In terms of cultural and ecological stability, the Temiar community might experience more difficulty accessing traditional areas, hunting zones, and sacred spaces. As these cultures rely on intact forest systems for medicinal herbs, food, and ritual practices, the anticipated loss poses not just an ecological but also a socio-cultural hazard [19].

3.4 Effects on Local Ecosystem and Indigenous Communities

The Temiar indigenous people, who have lived in the Nenggiri River Basin for generations, depend significantly on forest ecosystems for their survival. Loss of forest cover results in a reduction in the availability of medicinal herbs, sustenance (wild fruits, game), and materials for rituals and housing. The continuous loss of forest cover has significantly decreased the availability of these resources, as seen by the drop from 97.29% in 2005 to only 80.35% in 2024. Although this deforestation driven by commercial interests, it results in ecosystem distruption, biodiversity loss, and the destruction of natural ecosystems that are vital to the survival of both non-human and human life.

Deterioration of river health is one of the most direct environmental effects of forest degradation in the basin [20]. Forests act as naturals filters to control water flow, maintain soil stability, and stop excessive sedimentation [21]. As the forest's cover disappears, increasing surface runoff causes higher rates of erosion, which elevates sediment loads in rivers. This sedimentation might effects the aquatic photosynthesis, risks the aquatic ecosystem, and lower water quality. The loss of riparian buffers also causes thermal pollution because exposed riverbanks cause water temperatures to fluctuate, which stresses aquatic life [22,23].

Furthermore, the conversion of forested land into agriculture from 0.19% in 2005 to more than 3.16% in 2024—and open spaces from 2.25% in 2005 to more than 15.23% in 2024—has dramatically increased the concentrations of fertilizers, agrochemicals, and organic matter in neighboring rivers. Fertilizer runoff from plantations, as well as slash-and-burn techniques, promote eutrophication, resulting in algal blooms and reduced oxygen levels in aquatic systems [24]. These changes degrade the habitat of native freshwater species, some of which are now in decline and essential food supplies for the local population. The river basin's resistance to external disruptions and climate change is further weakened by this ecological stress.

The decline in forest condition has an impact on terrestrial biodiversity as well. Insects, birds, and mammals are among the many unique species that need on uninterrupted forest environments to survive [25]. Habitat destruction limits their mobility, isolates populations, and makes them more vulnerable to disease and predator [26]. Consequently, this puts away the natural processes that keep the forest ecosystem in balance, like pollination, seed distribution, and insect management. For example, in Gua Musang, Kelantan there have been reports of tigers killing Temiar community members and elephants destroying traditional farming plots due to habitat degradation[27,28]. These examples highlight the serious conflicts that exist between humans and wildlife as a result of biodiversity loss and forest degradation.

Although there are significant socioeconomic effects on the Temiar community, a larger regional threat is posed by the long-term environmental degradation. The Nenggiri River Basin is an important part of regional hydrology since it provides water to residents and ecosystems downstream. Continued ecological harm may result in more frequent and severe droughts, landslides, and flooding, especially as climate variability rises [29,30]. Thus, maintaining the ecological integrity of the basin is essential for both the long-term environmental security of the area and the survival of the indigenous population.

4. CONCLUSION

This study demonstrates the integration of geographical information system (GIS) and CA-Markov modelling in forecasting land use and land cover (LULC) changes in the Nenggiri River Basin. The study areas were rich with ecological and socio-cultural significance especially for the Temiar indigenous community. Findings revealed a notable decline in forested areas from 97.29% in 2005 to 80.35% in 2024, while agricultural and open space area remains increase. The model predicts that by 2040, the forest areas would further decrease to 60.05% with agricultural areas increase to 3.16% and open space areas increase to 15.23%. These land use changes, caused by development and agricultural growth, endanger ecological sustainability and the livelihoods of Temiar indigenous tribes, which rely significantly on forest resources. The forecasting results highlight the importance of sustainable land management techniques and legislative changes must be implemented to strike a balance between environmental preservation and development.

5. ACKNOWLEDGEMENTS

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