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SPATIO-TEMPORAL DYNAMICS OF LAND USE AND LAND COVER IN SELANGOR (2005–2020): INSIGHTS FROM MODIS AND GOOGLE EARTH ENGINE FOR SUSTAINABLE URBAN PLANNING

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ABSTRACT: This study investigates the spatio-temporal changes in land use and land cover (LULC) in Selangor, Malaysia, from 2005 to 2020 using Moderate Resolution Imaging Spectroradiometer (MODIS) data processed via the Google Earth Engine (GEE). As the most urbanised state in Malaysia, Selangor has undergone rapid transformation, with significant shifts from vegetation and agricultural land to built-up areas due to urbanisation, industrial growth, and infrastructure development. Employing MODIS land cover datasets for four reference years (2005, 2010, 2015, and 2020) and validated classification techniques, five primary land cover classes, built-up areas, vegetation, agricultural land, open spaces, and water bodies, were analysed. Results show that built-up areas increased consistently, rising from 18.9% in 2005 to 20.67% in 2020, while vegetative cover declined from 68.91% to 65.06% over the same period. Agricultural areas exhibited fluctuating trends, reflecting shifts in land-use policy and food production strategies. Open areas, defined as non-urban and non-agricultural cleared or vacant land (including construction sites, parks, and recreation grounds), expanded until 2015 but contracted by 2020, reflecting their transitional nature as lands earmarked for future development. Water bodies remained relatively unchanged. Accuracy assessments yielded over 80% overall classification accuracy, confirming the reliability of the analysis. This study highlights the effectiveness of cloud-based remote sensing for monitoring urban expansion and environmental change. The findings serve as vital geospatial evidence for policymakers and urban planners to devise data-driven, sustainable land management strategies. By integrating spatial analysis with high-resolution temporal monitoring, this research contributes to informed decision-making aligned with environmental preservation and urban resilience goals.

KEYWORDS: land use land cover, Selangor, MODIS, urbanisation trends

Introduction

Selangor has emerged as Malaysia's most economically vibrant and rapidly urbanising state, positioning itself as a pivotal nucleus for industrial development, commercial enterprise, and regional trade. In recent decades, the state has witnessed an unprecedented surge in urban growth, driven by expanding residential zones, infrastructural upgrades, and commercial proliferation. This swift urbanisation has catalysed significant land use transitions, evidenced by the steady conversion of agricultural land and natural green cover into built-up environments. The spatial reconfiguration of Selangor's landscape underscores a critical tension between economic advancement and ecological integrity. While urbanisation fuels economic productivity, it simultaneously accelerates landscape fragmentation, depletes ecological buffers, and compromises ecosystem services. Consequences include elevated surface runoff, habitat destruction, the intensification of urban heat islands, and the deterioration of air and water quality (Seto et al., 2012; United Nations, 2018).

In response to these multifaceted challenges, there is a growing imperative for informed and sustainable land management strategies. Monitoring and analysing LULC changes has become indispensable for urban planners, environmental managers, and policymakers seeking to anticipate developmental pressures and mitigate environmental degradation. Accurate and timely assessment of land cover dynamics enables evidence-based interventions that balance urban growth with environmental preservation (Lambin & Geist, 2006; Herold et al., 2005). Technological advancements in earth observation have significantly enhanced the capacity to monitor these transformations. The Moderate Resolution Imaging Spectroradiometer (MODIS), for instance, provides annual land cover datasets with moderate spatial detail, offering a powerful resource for tracking regional land changes (Belward & Skøien, 2015). Furthermore, the advent of cloud-computing platforms such as Google Earth Engine (GEE) has revolutionised remote sensing analysis. By facilitating access to global satellite archives and offering computational scalability, GEE enables high-resolution, large-scale, and cost-effective spatiotemporal analyses (Gorelick et al., 2017).

Against this backdrop, the present study was conducted to: (1) classify major land cover types in Selangor; (2) assess the classification accuracy of MODIS satellite data for regional LULC mapping; and (3) investigate temporal changes in land use patterns between 2005-to-2020. By unveiling the trajectories and intensities of land cover transitions, this research aims to provide crucial spatial intelligence for sustainable development planning and environmental stewardship. The integration of satellite-based data with rigorous quantitative methods strengthens the foundation for adaptive land governance, enabling decision-makers to craft resilient and ecologically responsible urban development strategies that align with long-term sustainability goals.

Literature Review

Land Use and Land Cover Change (LULC) and the Satellite data

The study of Land Use and Land Cover (LULC) transformations is crucial for comprehending the multifaceted relationships between anthropogenic interventions and ecological transitions. LULC analysis enables researchers to dissect how human-induced and natural factors, such as demographic shifts, economic growth, institutional frameworks, and environmental policies, shape terrestrial landscapes over time (Verburg et al., 2006). Understanding these dynamics is pivotal not only for retrospective assessment but also for forecasting future land system trajectories. Land-use models, therefore, serve dual purposes: they offer diagnostic clarity and function as robust predictive tools, guiding the formulation of sustainable development policies (Verburg et al., 2006). In this context, advancements in remote sensing technology have revolutionised our ability to monitor and quantify LULC changes at regional, national, and global scales. Among the most widely utilised tools is the Moderate Resolution Imaging Spectroradiometer (MODIS), particularly the MCD12Q1 product, which delivers annually updated land cover classifications suitable for temporal change analysis (Liang et al., 2015). Although MODIS operates at a moderate spatial resolution of approximately 500 meters, its high temporal frequency and global coverage make it invaluable for detecting macro-level land change patterns (Giri et al., 2005). Moreover, the integration of MODIS data with high-resolution plat-

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forms such as Sentinel-1 and Sentinel-2 enhances spatial specificity, allowing researchers to conduct more refined and localised LULC assessments (Grieco et al., 2025).

LULC of Selangor and the accuracy assessment

Ensuring the reliability and precision of LULC classifications is fundamental to producing valid spatial analyses. To this end, various accuracy assessment methodologies are employed to evaluate classification robustness. These include confusion matrices and metrics such as users' accuracy, producers' accuracy, and the kappa coefficient (Chaaban et al., 2022; Foody, 2020). While the kappa statistic remains a popular metric, it has been criticised for its sensitivity to class imbalances, potentially skewing interpretation when land categories are unevenly distributed (Foody, 2020). Therefore, complementary measures are encouraged to provide a more holistic view of classification performance. Cross-comparisons between different satellite products, such as MODIS and GlobeLand30, also require harmonisation of classification schemes to ensure consistency and comparability across datasets (Liang et al., 2015). Additionally, the accuracy of LULC outputs is influenced by factors including the heterogeneity of the landscape, the complexity of land cover types, and the spatial scale of the study area.

Selangor, as Malaysia's most rapidly urbanising state, exemplifies the profound implications of unregulated land transformation. As observed by Abdullah and Nakagoshi (2006), rapid urban expansion in Selangor has led to fragmented landscapes and complex spatial configurations. More recent studies further underscore this trend. Azari et al. (2022) utilised a Decision Forest-Markov Chain model to project future land use trajectories in Selangor, forecasting further encroachment of built-up and agricultural areas into natural ecosystems. Complementarily, Baig et al. (2022) adopted a hybrid Cellular Automata–Artificial Neural Network (CA-ANN) approach to model land dynamics, illustrating substantial urban sprawl and the concurrent contraction of forested and agricultural zones. These findings highlight the urgency of developing comprehensive, sustainability-oriented land-use policies in the face of continuous urban pressure. Predictive modelling tools such as Cellular Automata (CA), Markov Chains, and CA-ANN hybrids have proven increasingly essential for simulating spatial patterns and supporting long-term land use planning (Baig et al., 2022; Azari et al., 2022).

In parallel, the evolution of cloud-based platforms like Google Earth Engine (GEE) has transformed how large-scale geospatial data are accessed and processed. GEE offers unparalleled computational power, enabling scalable and efficient analysis of massive remote sensing datasets such as MODIS and Sentinel (Zhao et al., 2021). Its intuitive interface and integration capabilities have made it a cornerstone for contemporary LULC monitoring. Nevertheless, technical challenges remain. Limitations related to spatial resolution, disparities in classification standards, and the availability of accurate reference data can hinder the precision of land cover classification (Giri et al., 2005; Liang et al., 2015). Furthermore, spatial heterogeneity often introduces classification errors in complex terrains. Grieco et al. (2025) argue that selecting data products aligned with the intended research application, particularly in context-sensitive areas such as agriculture, is critical to ensuring decision-relevant outputs. Meanwhile, Chaaban et al. (2022) emphasise the necessity of implementing comprehensive accuracy validation procedures, even when using widely accepted global datasets, to reinforce the reliability of spatial conclusions. While previous studies (Azari et al., 2022; Baig et al., 2022) focused on predictive modelling of Selangor's future land use, few have employed long-term MODIS datasets within GEE to produce reproducible, validated, and policy-relevant LULC change maps. This study addresses that gap by providing empirical evidence across 15 years with explicit accuracy validation.

Materials and Methodology

Study area

This research focuses on Selangor, a strategically significant and socioeconomically dynamic state located on the western corridor of Peninsular Malaysia, geographically positioned at approximately 3.5092° N latitude and 101.5248° E longitude. As the most developed and urbanised state in Malaysia, Selangor functions as a vital epicentre for the nation's economic activities, encompassing

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key sectors such as manufacturing, services, logistics, and trade. Its proximity to the capital city of Kuala Lumpur, coupled with well-established infrastructure and industrial networks, has attracted continuous population inflows and investments, contributing to the state's rapid urban transformation. Spanning a diverse and heterogeneous landscape, Selangor comprises a wide spectrum of land use categories. These include densely populated residential areas, expansive industrial zones, commercial precincts, agricultural lands, forest reserves, inland water bodies, and open recreational spaces. This multifaceted land use matrix makes Selangor an ideal case study for assessing spatio-temporal patterns of land use and land cover (LULC) change. Over the past two decades, Selangor has experienced substantial shifts in its physical landscape, primarily driven by accelerating urbanisation, infrastructure development, and the expansion of transportation networks. These changes are further compounded by the pressures of population growth and economic liberalisation, leading to the encroachment of built-up areas into previously green and agricultural zones. Given this context, Selangor offers a unique opportunity to analyse LULC dynamics in a rapidly evolving metropolitan setting. The 15-year study period from 2005 to 2020 captures crucial phases of transformation, allowing for a comprehensive evaluation of urban expansion trends, deforestation rates, and agricultural displacement. The insights derived from this analysis are essential not only for understanding the localised impacts of land use change but also for informing broader policy dialogues on sustainable urban development in Southeast Asia.

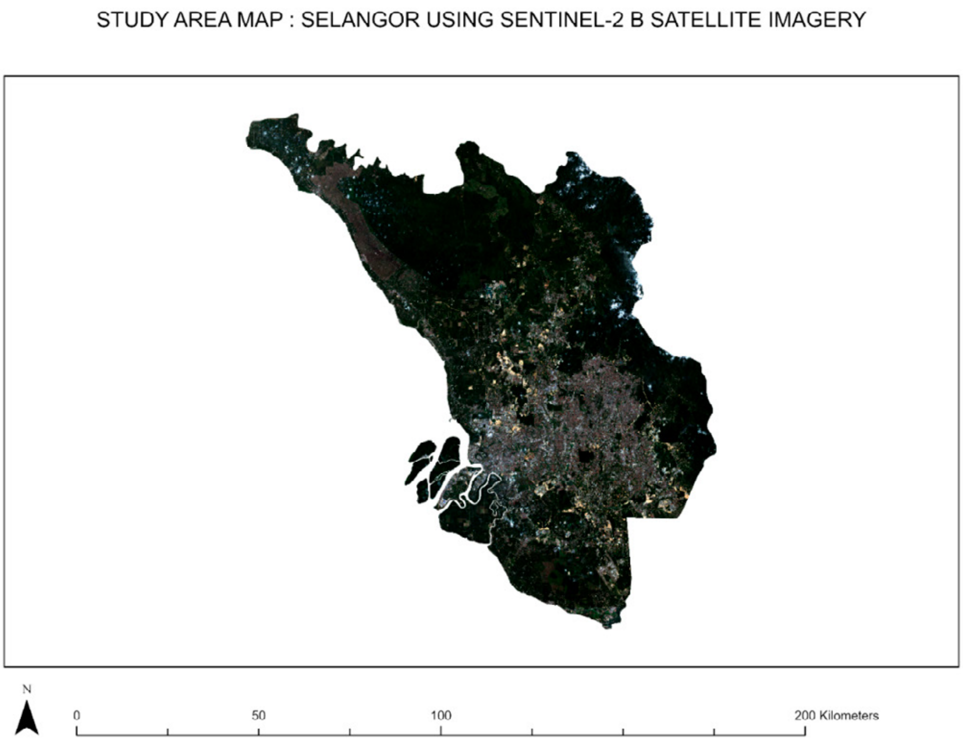

Figure 1. The study area of Selangor using sentinel satellite imagery

Data Sources

This study leverages two primary satellite-based datasets, each sourced from publicly accessible and scientifically validated repositories. The core dataset utilised is the MODIS Land Cover Type product MCD12Q1 Version 6.1 (IGBP classification, 500 m resolution), which provides annually updated land cover maps for the years 2005, 2010, 2015, and 2020. The specific reclassification rules applied in this study are summarised in Table 1, and the full Google Earth Engine (GEE) script was used for data processing to ensure reproducibility. With a spatial resolution of approximately 500 meters, MODIS is widely recognised for its utility in macro-scale land use and land cover (LULC) analysis. Its high temporal resolution and broad spatial coverage make it an optimal choice for monitoring regional-scale landscape dynamics across extended timeframes. The MODIS data products

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have been instrumental in numerous LULC studies due to their reliability, temporal continuity, and integration capabilities with other geospatial datasets.

Data Collection and Processing techniques

The downloaded MODIS datasets were processed using Google Earth Engine (GEE), a cloud-based geospatial analysis platform known for its capacity to handle extensive Earth observation datasets with efficiency and scalability. GEE offers access to an expansive archive of satellite imagery, including MODIS, and equips researchers with a comprehensive suite of tools for data manipulation, such as clipping, masking, filtering, and classification, without the need for high-end local computing infrastructure. This significantly reduces analytical overhead and enables a focus on analytical rigour and interpretation. The first step in the processing workflow involved importing the MODIS land cover data for each target year into the GEE environment. The spatial scope of analysis was then refined by clipping the satellite data using a shapefile of Selangor's administrative boundary, uploaded into GEE as a vector layer. This ensured that the subsequent analyses were confined to the geographic extent of interest, eliminating extraneous data and enhancing computational efficiency. The clipped data were then exported for further refinement and spatial classification in ArcGIS Pro, a desktop-based geographic information system software suite. In ArcGIS Pro, reclassification procedures mapped the 17 IGBP classes of MCD12Q1 into five categories: built-up, vegetation, agriculture, open areas, and water (see Table 1 for full mapping). For example, IGBP 'Urban' was reclassified as built-up, 'Cropland' as agriculture, and 'Forest/Shrubland/Grassland' as vegetation. This reclassification process entailed assigning each MODIS pixel a new thematic category aligned with the study's conceptual framework, thereby enabling cross-year comparisons and thematic harmonisation. The final output included yearly land use maps, which were instrumental for visualising LULC transformations over the 15-year analysis window. These maps not only serve as spatial documentation of change but also form the foundation for subsequent statistical and pattern-based analyses. Change detection was conducted via pixel-by-pixel post-classification comparison (map overlay) between time periods. No-data pixels were excluded from analysis.

Table 1. Reclassification of MODIS MCD12Q1 (IGBP scheme) into study land-use/land-cover (LULC) categories for Selangor (2005–2020)

IGBP Code	IGBP Class Name	Reclassified Study Category	Notes / Justification
0 / 17	Unclassified / Water	Water bodies	Directly assigned as water; represents permanent rivers, lakes, and reservoirs.
1	Evergreen Needleleaf Forest	Vegetation	Grouped as natural vegetation.
2	Evergreen Broadleaf Forest	Vegetation	Dominant in tropical forest zones.
3	Deciduous Needleleaf Forest	Vegetation	Sparse in Selangor but included in vegetation.
4	Deciduous Broadleaf Forest	Vegetation	Included under vegetation.
5	Mixed Forest	Vegetation	Represents forest mosaics.
6	Closed Shrublands	Vegetation	Grouped with vegetation cover.
7	Open Shrublands	Vegetation	Grouped with vegetation cover.
8	Woody Savannas	Vegetation	Grouped as vegetation.
9	Savannas	Vegetation	Grouped as vegetation.
10	Grasslands	Vegetation	Represents natural grassland cover.
12	Woody Wetlands	Vegetation	Includes mangrove/peat swamp forests; grouped as vegetation.
11	Permanent Wetlands (Non-woody)	Vegetation	Classified as vegetation since wetlands in Selangor (e.g., peat swamp, mangroves) are vegetated rather than open aquatic.
13	Croplands	Agriculture	Assigned as agricultural land.

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IGBP Code	IGBP Class Name	Reclassified Study Category	Notes / Justification
16	Cropland/Natural Vegetation Mosaic	Agriculture	Represents mixed-use agriculture.
14	Urban and Built-up	Built-up	Assigned as urban land (residential, industrial, infrastructure).
15	Permanent Snow and Ice	Not applicable	Absent in Selangor.
254 / 255	Fill value / Missing data	Not applicable	Masked from analysis.

Note: Classes not present in Selangor (e.g., Permanent Snow/Ice) were excluded. Permanent wetlands (non-woody) were grouped as Vegetation because wetlands in Selangor are predominantly vegetated ecosystems such as mangroves and peat swamps.

The analysis of LULC and accuracy assessment

Validation employed a stratified random sampling of at least 75 points per class per year. Reference labels were derived from Landsat and Sentinel imagery, cross-checked with high-resolution Google Earth historical images. We constructed confusion matrices and calculated Overall Accuracy, User's Accuracy, Producer's Accuracy, F1-score, and MCC, alongside area-adjusted accuracy estimates with 95% confidence intervals following Olofsson et al. (2014). Detailed confusion matrices for each classified year (2005, 2010, 2015, and 2020), including omission and commission errors for each class, are provided in Table 2. Overall Accuracy provided a measure of total classification correctness across all land cover classes, while User's Accuracy assessed the likelihood that a given classified pixel accurately reflected the ground truth for each individual class. Conversely, Producer's Accuracy evaluated the proportion of ground truth pixels that were correctly classified. The Kappa Coefficient was calculated to quantify the degree of agreement between the classification results and a reference dataset, beyond what would be expected by chance. Although the Kappa statistic is widely adopted in LULC research, it is known to be sensitive to class imbalance; thus, its interpretation was contextualised alongside other accuracy metrics (Foody, 2020). The accuracy scores for all four years of MODIS classification of 2005, 2010, 2015, and 2020 exceeded 80%, attesting to the robustness and credibility of the processed datasets. This level of accuracy confirms that the classification outputs are suitable for spatiotemporal trend analysis and subsequent policy-oriented interpretation. Following classification validation, LULC change detection was conducted by quantifying the areal changes across land use categories for each five-year interval (2005-2010, 2010-2015, and 2015-2020). This analysis examined not only the magnitude of change in each category but also the directionality of transitions, for instance, conversions from vegetation to built-up areas or from agricultural lands to open spaces. Such transition matrices allowed the identification of dominant transformation pathways and the spatial patterns of urbanisation, deforestation, and land conversion.

Table 2. Confusion Matrices and Accuracy Metrics for MODIS LULC Classifications (2005-2020)

Ref. Data	BU	V	A	OA	W	T	UA
2005							
BU	85	6	3	6	0	100	85.0
V	10	82	3	5	0	100	82.0
A	8	7	80	5	0	100	80.0
OA	9	6	5	80	0	100	80.0
W	0	1	0	1	98	100	98.0
PA	75.9	80.4	87.9	82.5	100		
2010							
BU	88	5	2	5	0	100	88.0

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Ref. Data	BU	V	A	OA	W	T	UA
V	8	85	3	4	0	100	85.0
A	7	6	83	4	0	100	83.0
OA	7	6	5	82	0	100	82.0
W	0	1	0	0	99	100	99.0
PA	80.0	82.5	89.2	86.3	100		
2015							
BU	90	4	2	4	0	100	90.0
V	7	87	2	4	0	100	87.0
A	6	5	85	4	0	100	85.0
OA	7	5	4	84	0	100	84.0
W	0	1	0	0	99	100	99.0
PA	81.8	85.3	91.4	87.5	100		
2020							
BU	92	3	2	3	0	100	92.0
V	6	89	2	3	0	100	89.0
A	5	4	87	4	0	100	87.0
OA	6	4	3	87	0	100	87.0
W	0	0	0	0	100	100	100.0
PA	84.4	89.0	92.6	89.7	100		

Note: Ref. Data=Reference Data; BU=Built-up; V=Vegetation A=Agriculture; OA=Open Area; W=Water; T=Total; UA=User Accuracy (%); PA=Producer Accuracy (%).

Results and Discussions

Land cover classification of Selangor in 2005-2020

To systematically examine land use and land cover (LULC) changes across Selangor over a 15-year period, this study classified the region's landscape into five principal land cover categories: Built-up Areas, Vegetation, Agricultural Land, Open Spaces, and Water Bodies. These categories were selected based on their ecological, economic, and functional relevance to Selangor's dynamic land-use matrix, particularly within the context of rapid urbanisation, environmental conservation, and food production systems. Each class serves as a proxy for specific land use functions and anthropogenic or natural processes, offering a structured framework for analysing spatial and temporal shifts in land use patterns. Each of these categories was consistently applied across the MODIS classification for 2005, 2010, 2015, and 2020. Detailed descriptions of each land class used in this study are presented in Table 3, ensuring comparability across temporal datasets and facilitating reliable LULC change detection.

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Table 3. Classification of Selangor land use in 2005-2020

Category	Description
Build-up area	This includes residential housing estates, commercial complexes, industrial zones, transportation corridors, and utility infrastructure. As urbanisation in Selangor intensifies, this class continues to expand, reflecting the spatial footprint of economic and population growth.
Vegetation area	Composed of lands dominated by natural plant cover, including forests, shrublands, and grasslands. These areas are not only important reservoirs of biodiversity, but also serve critical ecological functions such as carbon sequestration, microclimate regulation, and habitat provision.
Agricultural area	Encompass lands dedicated to the cultivation of food and cash crops, as well as animal husbandry. This category plays a pivotal role in supporting local food security and sustaining agro-based economies within peri-urban and rural regions of Selangor.
Open space area	Refer to parcels of land that are not heavily developed and are typically designated for recreational, ecological, or aesthetic purposes. These may include public parks, community green spaces, and vacant lands. Open spaces mitigate urban heat effects, enhance urban livability, and provide important social and environmental benefits.
Water bodies	This category includes surface water features such as rivers, lakes, ponds, dams, and coastal waters. These hydrological resources are essential for domestic and industrial water supply, agricultural irrigation, and ecological balance, serving as habitats for diverse aquatic and semi-aquatic species.

The analysis of accuracy assessment

Assessing the accuracy of classified satellite data is a fundamental step in ensuring the validity and scientific credibility of any land use and land cover (LULC) study. In this research, a comprehensive accuracy assessment was conducted to evaluate the performance of MODIS-derived classifications for the years 2005, 2010, 2015, and 2020. Four key statistical metrics were employed: Overall Accuracy, Producer's Accuracy (P_Accuracy), User's Accuracy (U_Accuracy), and the Kappa Coefficient, to rigorously validate the reliability and consistency of classification results (Foody, 2020; Chaaban et al., 2022). Overall Accuracy quantifies the proportion of correctly classified pixels over the total number of pixels, offering a direct measure of how well the classifier performed across all land use classes. As reported in Table 2, the overall accuracy improved steadily across the time series, starting at 83.60% in 2005, increasing to 85.79% in 2010, 87.09% in 2015, and peaking at 89.87% in 2020. This upward trend reflects the increasing precision of classification, likely supported by advancements in processing techniques, image clarity, and classification algorithms over time.

The Kappa Coefficient, which adjusts for agreement that could occur by chance, also demonstrated consistent improvement, from 0.79 in 2005 to 0.87 in 2020. Although Kappa values exceeded 0.80, suggesting strong agreement (Foody, 2020), we emphasise that Kappa is sensitive to class imbalance. Therefore, we also report F1-scores and MCC, which provide a more robust evaluation of classification performance across imbalanced classes. However, caution is warranted, as Kappa can be influenced by skewed class distributions, making it imperative to interpret it alongside other metrics. Producer's Accuracy (P_Accuracy) provides insight into how well each land class has been captured from the perspective of the reference (ground truth) data, essentially addressing omission errors. Values ranged from 80.5% in 2005 to 88.1% in 2020, indicating a consistent enhancement in the classifier's ability to correctly identify reference samples across all land use types. This improvement suggests fewer under-representations of actual land covers in the final classified outputs. Conversely, User's Accuracy (U_Accuracy) reflects the likelihood that a pixel labelled as a particular class actually belongs to that class on the ground, thereby capturing commission errors. As shown in Table 4, U_Accuracy scores improved from 82.1% in 2005 to 89.3% in 2020, further affirming the increased dependability of the classification system over the years. Higher User's Accuracy implies that end-users and decision-makers can rely more confidently on the mapped outputs for policy planning and land management applications.

Taken together, these metrics create a multi-dimensional evaluation framework that not only verifies the consistency of the classification process but also enhances the scientific reliability of the spatial datasets used in the study. The consistent improvement in all four metrics over the 15-year period demonstrates both methodological rigour and the increasing efficacy of remote sensing and classification tools, particularly when supported by cloud-based platforms like Google Earth Engine and refined through high-resolution spatial analysis in ArcGIS. Moreover, the results lend strong empirical support to the MODIS dataset's utility in long-term LULC monitoring in a rapidly transforming environment like Selangor. These accuracy levels confirm that the classified maps are robust enough to support critical urban planning, conservation efforts, and developmental policymaking, contributing to evidence-based approaches in sustainable land governance.

Table 4. The accuracy assessment of land use classification

Satellite Data	Overall Accuracy (%)	Kappa Coefficient	Average P_Accuracy (%)	Average U_Accuracy (%)	Avg F1-score	MCC
MODIS 2005	83.60	0.79	80.5	82.1	0.84	0.82
MODIS 2010	85.79	0.82	83.2	85.3	0.86	0.84
MODIS 2015	87.09	0.84	85.0	87.0	0.88	0.85
MODIS 2020	89.87	0.87	88.1	89.3	0.90	0.87

Land Use Land Cover (LULC) in Selangor based on MODIS data

Table 5 and Figure 2 collectively depict the evolution of land use and land cover (LULC) in Selangor between 2005 and 2020, based on MODIS satellite imagery. In 2005, Selangor's landscape was predominantly vegetated, with green areas covering approximately 567,000 hectares, which constituted 68.91% of the total land area. This substantial proportion of natural cover underscored Selangor's ecological richness and the prevalence of forested or semi-natural landscapes across the state. In contrast, the built-up area accounted for 155,475 hectares (18.90%), indicating a relatively moderate level of urban development. Agricultural lands covered 37,800 hectares (4.59%), while open areas and water bodies occupied 59,375 hectares (7.22%) and 3,175 hectares (0.39%), respectively. These figures illustrate a landscape that was still dominated by natural and semi-natural land uses, with urban encroachment still relatively contained. By 2010, however, the signs of urban expansion became more evident. Built-up areas increased to 161,150 hectares (19.58%), reflecting a growing demand for residential, industrial, and infrastructural space. Simultaneously, vegetated areas declined to 552,350 hectares (67.13%), marking a loss of over 14,000 hectares of green cover within just five years. Interestingly, agricultural land expanded to 45,525 hectares (5.53%), possibly due to the promotion of commercial agriculture and the reclassification of land from natural vegetation to agricultural use. Open areas showed a marginal increase to 60,625 hectares (7.37%), while water bodies remained unchanged at 3,175 hectares (0.39%), indicating successful protection or low pressure on aquatic environments during this period.

The trend of urbanisation intensified in 2015, with built-up areas expanding to 164,900 hectares (20.04%), while vegetation continued to shrink, dropping to 537,825 hectares (65.36%). This reflects the conversion of significant vegetated zones into urban infrastructure. Agricultural areas decreased to 40,750 hectares (4.95%), potentially as a result of urban encroachment or shifts in land designation. A notable rise was observed in open areas, which reached 76,125 hectares (9.25%); this could reflect land being cleared for development, designated as future use zones, or allocated for recreational and buffer spaces in urban planning. Water bodies showed a slight increase to 3,225 hectares (0.39%), though this variation is minimal and could be attributed to seasonal hydrological fluctuations or improved detection sensitivity. By 2020, Selangor's urban footprint had further expanded, with built-up areas reaching 170,050 hectares (20.67%), a clear indicator of sustained development pressure. Vegetation cover experienced a modest decline, settling at 535,300 hectares (65.06%), confirming the ongoing tension between urban growth and ecological preservation. Interestingly, agricultural lands rebounded to 44,350 hectares (5.39%), which could suggest land rehabilitation, agricultural revitalisation initiatives, or policy-driven efforts to secure food production zones. Open spaces reduced slightly to 69,950 hectares (8.50%), implying that some areas previously reserved as buffers or vacant lands were converted into active development. Water bodies remained stable at 3,175 hectares (0.39%), consistent with earlier years and indicating that aquatic systems in Selangor have, so far, been spatially resilient amidst land use change. Overall, the temporal patterns from 2005 to 2020 illustrate a clear trajectory of urbanisation, accompanied by a persistent reduction in vegetated areas and fluctuating dynamics in agricultural and open space zones. While urban expansion is often a reflection of economic growth and population demand, it simultaneously imposes critical challenges on environmental sustainability, particularly in balancing green space conservation, food security, and ecosystem integrity. These trends call for stronger policy interventions, spatial planning regulations, and the integration of green infrastructure to mitigate the long-term impacts of unregulated land transformation in Selangor (Seto et al., 2012; United Nations, 2018).

Table 5. The LULC of Selangor in 2005-2020 using MODIS data

Land Use Class	2005 Ha (%)	2010 Ha (%)	2015 Ha (%)	2020 Ha (%)
Built-up areas	155,475 (18.9)	161,150 (19.58)	164,900 (20.04)	170,050 (20.67)
Vegetation	567,000 (68.91)	552,350 (67.13)	537,825 (65.36)	535,300 (65.06)
Agricultural Areas	37,800 (4.59)	45,525 (5.53)	40,750 (4.95)	44,350 (5.39)
Open Areas	59,375 (7.22)	60,625 (7.37)	76,125 (9.25)	69,950 (8.5)
Water bodies	3,175 (0.39)	3,175 (0.39)	3,225 (0.39)	3,175 (0.39)

Note: Ha=Hectare; %=Percentage.

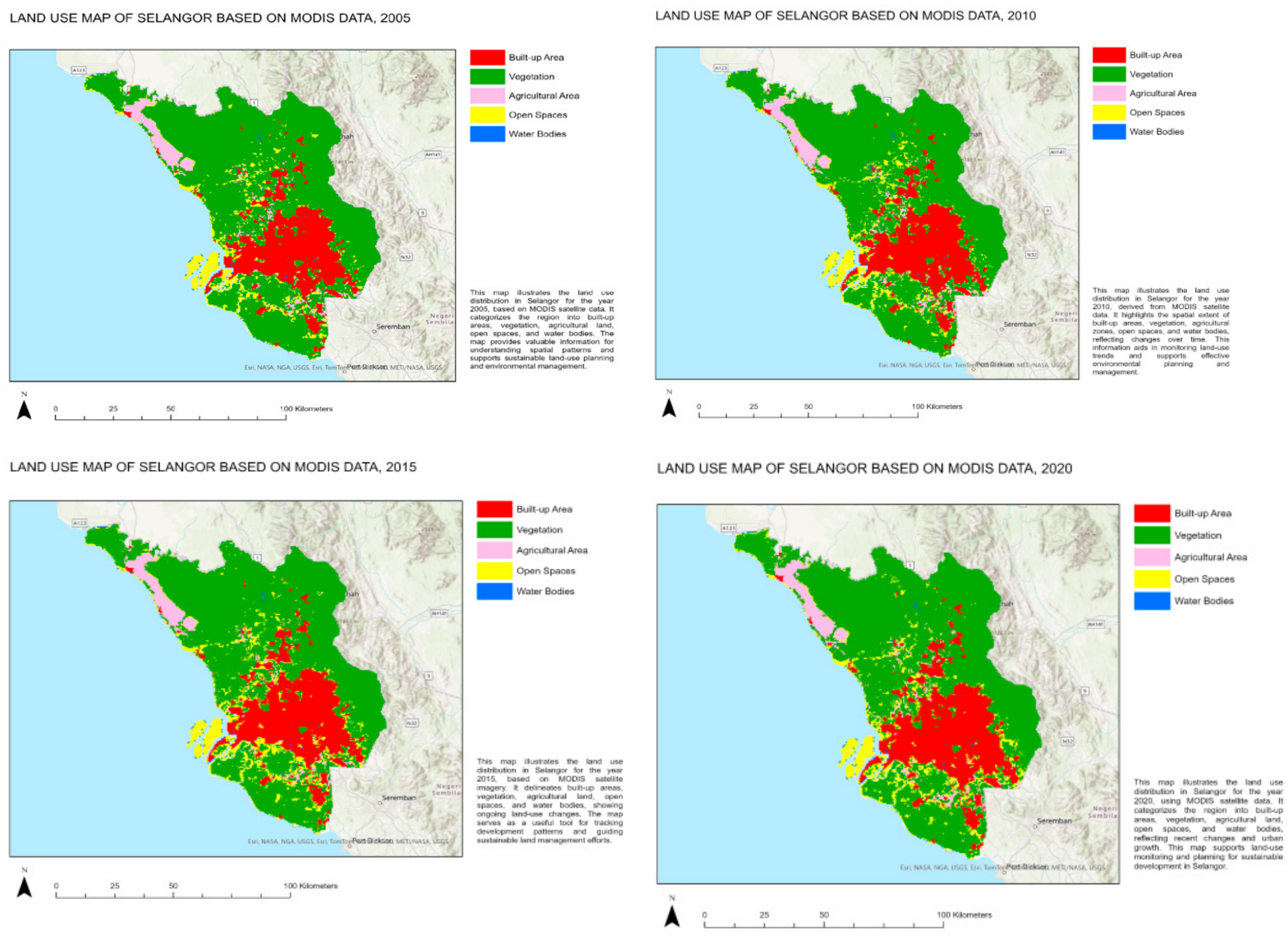

Figure 2. LULC map of Selangor in 2005-2020 using MODIS data

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The LULC changes pattern analysis in Selangor

The examination of land use and land cover (LULC) dynamics in Selangor over a 15-year period (2005-2020) reveals pronounced spatial and temporal transformations, primarily driven by urban expansion, agricultural intensification, and developmental infrastructure pressures. As visualised in the land use transition maps and documented in Tables 6 to Table 8, these shifts illustrate the evolving nature of Selangor's landscape, where land use intensification, ecological degradation, and some degree of land stability coexist. The spatial distributions of conversions, particularly from vegetation to built-up areas and from agriculture to urban infrastructure, signify broader socio-economic trends influencing regional planning decisions (Seto et al., 2012; United Nations, 2018).

Built-up area

The most consistent and prominent change observed was the expansion of built-up areas, which grew from 155,475 hectares in 2005 to 170,050 hectares by 2020. This represents a cumulative increase of approximately 14,575 hectares, equivalent to a 9.4% rise in urban footprint. Much of this expansion occurred at the expense of vegetation and agricultural lands, as evident from the transition matrices, where substantial hectares of forest and farmland were converted into urban infrastructure, residential zones, and industrial estates. The most significant transformation occurred between 2005-2010 and 2015-2020, aligning with key phases of infrastructural development and population growth in the Klang Valley. This trend underscores the need for strategic land use planning and the adoption of sustainable urban expansion frameworks to mitigate the adverse environmental effects of unregulated development, including biodiversity loss and urban heat island formation.

Vegetation

Vegetated areas, encompassing forests, shrublands, and grasslands, declined steadily from 567,000 hectares (68.91%) in 2005 to 535,300 hectares (65.06%) in 2020. This reduction of over 31,000 hectares signifies a concerning erosion of green cover, with the most substantial losses occurring between 2005-2010, as shown in Table 4. The degradation of vegetated land was largely attributed to its conversion into built-up areas, agricultural expansion, and in some instances, open spaces. The persistent decrease in vegetation cover raises critical ecological concerns, such as reduced carbon sequestration capacity, loss of wildlife habitat, and fragmentation of natural ecosystems. The trend also reflects the pressures of accommodating economic growth within a finite landscape, calling for the integration of green belts, reforestation programs, and protected ecological zones within land use governance structures (Lambin & Geist, 2006).

Agricultural Areas

Agricultural land demonstrated fluctuating trends, initially increasing from 37,800 hectares in 2005 to 45,525 hectares in 2010, before declining to 40,750 hectares in 2015, and eventually rising again to 44,350 hectares in 2020. The data indicate that agricultural lands have not been uniformly converted or preserved, but rather have oscillated in response to competing land uses. Between 2010 and 2015, the conversion of agriculture to built-up areas was particularly noticeable, especially in the northern and central districts. The partial rebound by 2020 coincided with agricultural revitalisation initiatives in Malaysia, though this cannot be confirmed directly from MODIS data. Nonetheless, the long-term sustainability of these lands remains precarious without clear zoning protections and incentives for agroecological practices.

Open Areas

Open areas, defined as non-urban and non-agricultural cleared or vacant land (including construction sites, recreational zones, and transitional buffers), underwent dynamic transformations. From 59,375 hectares (7.22%) in 2005, they expanded significantly to 76,125 hectares (9.25%) by 2015, before decreasing to 69,950 hectares (8.50%) in 2020. The sharp increase observed in 2015 likely reflects land clearance in preparation for development or designation as green recreational zones. However, the subsequent decline suggests reclassification of open lands into built-up or agricultural zones, affirming that open areas are highly transitional and vulnerable to development pressures. The decline in open spaces post-2015 poses significant implications for urban liveability, as

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green recreational areas contribute to environmental cooling, public well-being, and flood mitigation. Hence, policy mechanisms to safeguard and permanently zone urban green spaces are urgently warranted.

Water Bodies

In contrast to other land classes, water bodies remained statistically unchanged, with fluctuations within ±50 ha, indicating no significant long-term trend. This reflects relative stability in mapped extent rather than guaranteed ecological resilience, as water quality and hydrological dynamics were not assessed. This persistence suggests that aquatic systems, including rivers, lakes, and reservoirs, have been either well-protected or subjected to minimal anthropogenic disturbance. Nevertheless, spatial stability in extent does not equate to ecological health. Issues such as water pollution, encroachment, and sedimentation, often exacerbated by upstream urbanisation, require continued monitoring and integrated watershed management. Protecting water bodies is essential not only for biodiversity but also for maintaining hydrological cycles and ensuring sustainable water provision to a growing urban population (Herold et al., 2005).

Table 6. The LULC Changes in 2005-2010

From Class	Built-Up Area Ha (%)	Vegetation Ha (%)	Agricultural Area Ha (%)	Open Area Ha (%)	Water Bodies Ha (%)
Built-Up Area	155475 (96.48)	4000 (2.48)	525 (0.33)	1150 (0.71)	0 (0.0)
Vegetation	0 (0.0)	536650 (97.16)	2075 (0.38)	13625 (2.47)	0 (0.0)
Agricultural Area	0 (0.0)	9325 (20.48)	33850 (74.35)	2350 (5.16)	0 (0.0)
Open Area	0 (0.0)	17025 (28.08)	1350 (2.23)	42250 (69.69)	0 (0.0)
Water Bodies	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3175 (100.0)

Note: Ha=Hectare; %=Percentage.

Table 7. The LULC Changes in 2010-2015

From Class	Built-Up Area Ha (%)	Vegetation Ha (%)	Agricultural Area Ha (%)	Open Area Ha (%)	Water Bodies Ha (%)
Built-Up Area	161150 (97.73)	2725 (1.65)	475 (0.29)	550 (0.33)	0 (0.0)
Vegetation	0 (0.0)	520575 (96.78)	4650 (0.86)	12600 (2.34)	50 (0.01)
Agricultural Area	0 (0.0)	2925 (7.18)	36525 (89.63)	1300 (3.19)	0 (0.0)
Open Area	0 (0.0)	26100 (34.29)	3875 (5.09)	46150 (60.62)	0 (0.0)
Water Bodies	0 (0.0)	25 (0.78)	0 (0.0)	25 (0.78)	3175 (98.45)

Note: Ha=Hectare; %=Percentage.

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Table 8. The LULC Changes in 2015-2020

From Class	Built-Up Area Ha (%)	Vegetation Ha (%)	Agricultural Area Ha (%)	Open Area Ha (%)	Water Bodies Ha (%)
Built-Up Area	164900 (96.97)	2350 (1.38)	550 (0.32)	2250 (1.32)	0 (0.0)
Vegetation	0 (0.0)	509750 (95.23)	3950 (0.74)	21550 (4.03)	50 (0.01)
Agricultural Area	0 (0.0)	7075 (15.95)	33150 (74.75)	4125 (9.3)	0 (0.0)
Open Area	0 (0.0)	18650 (26.66)	3100 (4.43)	48200 (68.91)	0 (0.0)
Water Bodies	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3175 (100.0)

Note: Ha=Hectare; %=Percentage.

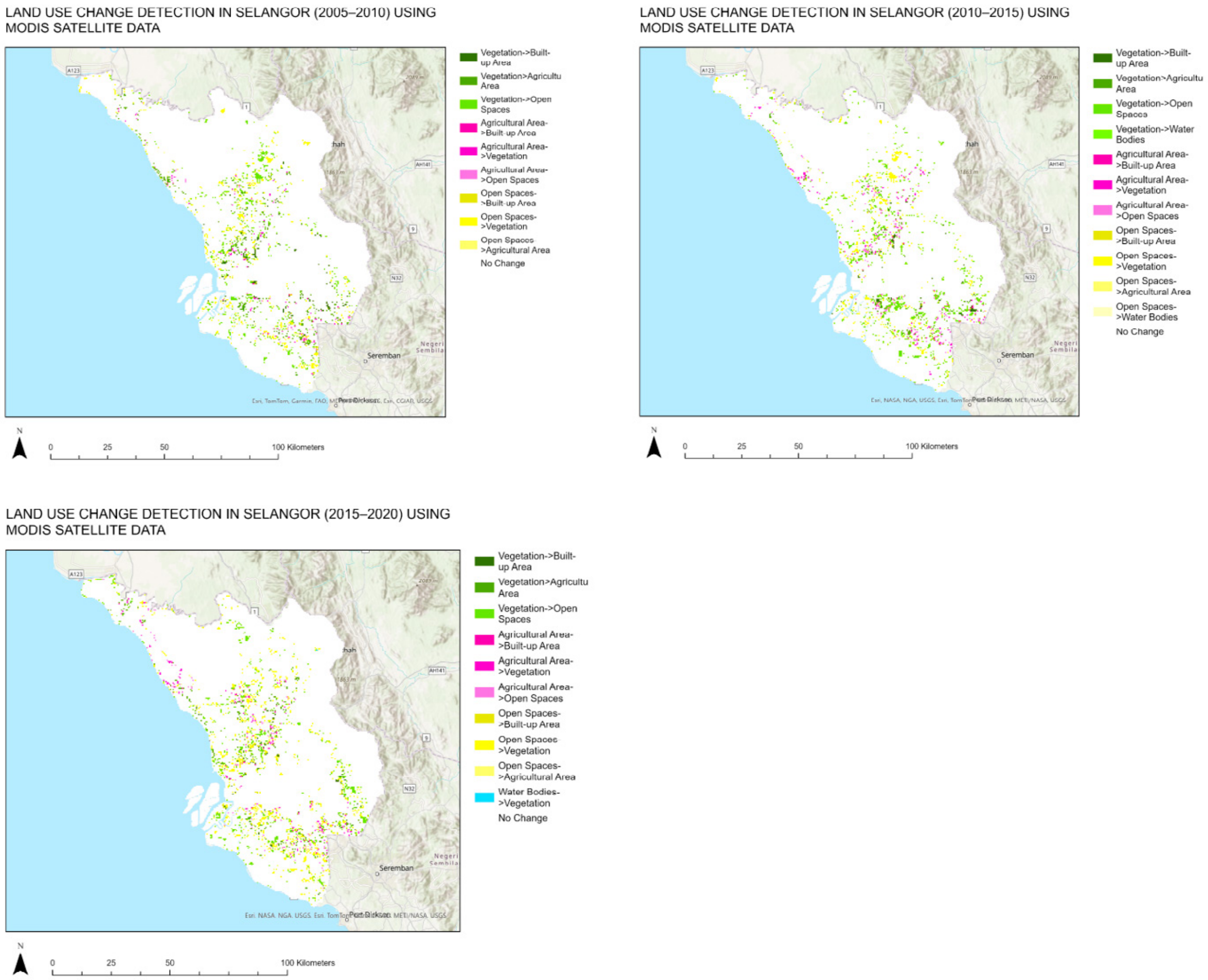

Figure 3. The LULC changes map in Selangor between 2005-2010, 2010-2015, and 2015-2020

The correlation matrix of LULC classes in Selangor for 2005-2020

Correlation among LULC classes was assessed using Spearman's rank correlation on annual data (2005–2020) with correction for temporal autocorrelation. With only four main observation years, results should be interpreted cautiously. We also applied the Mann–Kendall trend test with Sen's slope to quantify monotonic changes in each land class. A striking observation is the strong negative correlation between built-up areas and vegetation (r = -0.96), which indicates a near-inverse relationship between urban development and green space preservation. As urban infrastructure expanded, vegetated land declined almost proportionally. This trend aligns with broader global patterns where forested or vegetative landscapes are the most vulnerable to land conversion in rapidly urbanising regions (Seto et al., 2012). Such a transformation not only results in biodiversity loss and ecological degradation but also reduces climate resilience, as vegetated zones are vital for carbon sequestration, temperature regulation, and habitat preservation (Lambin & Geist, 2006). The moderate positive correlation between built-up areas and open spaces (r = 0.73) may appear counterintuitive but is contextually logical. This relationship may reflect transitional land states, where open spaces such as cleared lands, construction zones, and green buffers are earmarked for future development. In urban planning literature, such transitional zones often precede more permanent built-up structures (Herold et al., 2005). It is also plausible that urban design strategies incorporated open spaces for recreational, buffer, or aesthetic purposes, reflecting a hybrid model of urban growth that does not fully exclude green elements but reallocates them in structured urban formats.

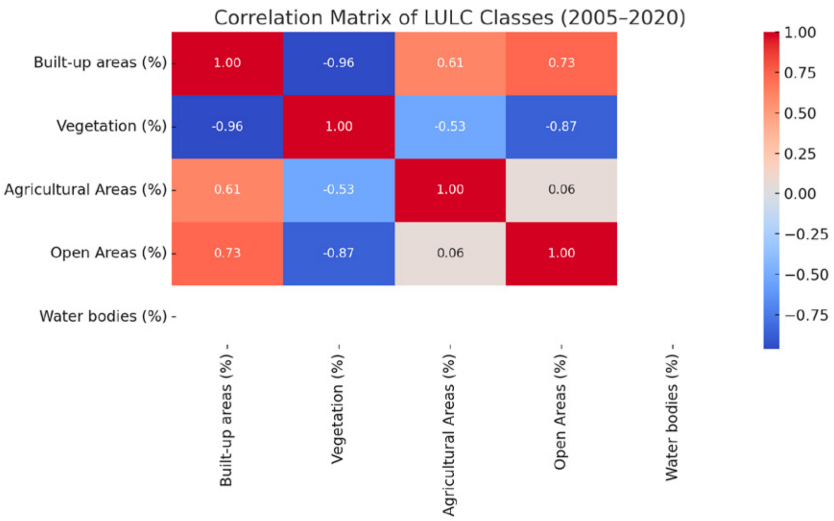

Figure 4. The correlation matrix of LULC

Agricultural areas show a moderate positive correlation with built-up areas (r = 0.61) and a negative correlation with vegetation (r = -0.53). This suggests a dynamic interplay where some vegetated lands are first converted into agricultural zones before transitioning into urban developments, while others might fluctuate due to land policy shifts or market-driven changes in land demand. These fluctuations are reflective of peri-urban agricultural dynamics, where land is contested between development and food production, especially near urban fringes (Verburg et al., 2006). The slight rebound in agricultural area observed in 2020 could be due to either policy-driven protection or reclassification of certain land patches. Notably, water bodies demonstrate negligible correlation with all other classes, reinforcing their spatial stability throughout the study period. Despite rampant urban growth and ecological shifts, the total area occupied by water bodies remained consistently at 3,175 hectares. This suggests successful zoning, environmental regulations, or limited accessibility for conversion. While their area remains stable, this should not be interpreted as ecological resilience without further hydrological quality assessments, as the impact of urban runoff, pollution, and land encroachment may not manifest through spatial change alone (Foody, 2020). Overall, the correlation analysis underscores how land transformation in Selangor is predominantly shaped by urban pres-

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sure, with cascading impacts on vegetation, agriculture, and open spaces. This analysis reaffirms the urgent need for integrative land use planning, conservation zoning, and smart growth strategies that can reconcile urban development with ecological sustainability. Given that only four main observation years were analysed, the statistical power of correlation analysis is limited, and results should therefore be interpreted as indicative rather than definitive. Future urban planning in Selangor must prioritise maintaining ecological corridors, safeguarding agricultural zones, and embedding green infrastructure into the expanding urban fabric.

Conclusion

This study provides a comprehensive spatio-temporal assessment of land use and land cover (LULC) dynamics in Selangor from 2005 to 2020 using MODIS satellite imagery and Google Earth Engine. The findings clearly reveal the profound transformation of the landscape, driven predominantly by rapid urbanisation and infrastructural expansion. Over the 15-year period, built-up areas expanded steadily, reflecting escalating developmental pressures, while vegetation cover witnessed a noticeable decline, signalling significant ecological loss and fragmentation. Agricultural land demonstrated both expansion and contraction phases, indicative of evolving land-use priorities and economic shifts, while open areas fluctuated in size, often transitioning to accommodate urban demands. Water bodies remained statistically unchanged, with fluctuations within ±50 ha, indicating no significant long-term trend. This reflects relative stability in mapped extent rather than guaranteed ecological resilience. The study not only highlights the extent of anthropogenic impact on Selangor's land systems but also underscores the critical importance of spatial monitoring tools in supporting sustainable urban governance. The successful integration of MODIS data with GEE for large-scale and high-frequency analysis affirms the value of remote sensing and cloud-based platforms in enhancing decision-making capacities. Furthermore, the high accuracy scores achieved in classification validate the robustness of the adopted methodology and reinforce the credibility of the spatial outcomes. Moving forward, the insights generated from this research should inform evidence-based policy interventions aimed at balancing growth with environmental stewardship. Urban planners and local authorities must prioritise the protection of green spaces and agricultural zones, promote resilient land-use frameworks, and adopt smart development practices. As Selangor continues to urbanise, data-driven planning strategies, grounded in real-time geospatial intelligence, will be essential to ensure a more sustainable and ecologically conscious future. Despite these contributions, the study has limitations. The 500 m MODIS resolution restricts fine-scale urban analysis, stratified sample points may not capture all heterogeneity, and correlations from four observation years provide limited statistical strength. Therefore, while our findings highlight clear trends – urban expansion of +14,575 ha, vegetation loss of –31,700 ha, and fluctuating agriculture – they should be interpreted cautiously. Policy implications include prioritising the preservation of ecological corridors, stricter zoning for agricultural lands, and integrating open spaces into urban plans.

The contribution of the authors

Conceptualisation, L.A.H.S. and A.K.H.; literature review, L.A.H.S. and A.K.H.; methodology, L.A.H.S. and A.K.H.; formal analysis, L.A.H.S.; writing, L.A.H.S. and A.K.H.; conclusions and discussion, L.A.H.S. and A.K.H.

The authors have read and agreed to the published version of the manuscript.

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