



Spatio-Temporal Trends in Land Conversion and Their Implications for Environmental Resilience: The Case of Malang Regency, 2015-2025

Monika Agustia^{1✉}, Sukma Sakti Agita Hermanto²

¹ Program Studi Teknologi Produksi Tanaman Hortikultura, Jurusan Teknologi Produksi Pertanian, Politeknik Pertanian Negeri Pangkajene Kepulauan, Indonesia

^{2,3} Program Studi Agroteknologi, Fakultas Sains dan Teknologi, Universitas Islam Raden Rahmat, Indonesia

ABSTRAK

Dinamika penggunaan dan penutupan lahan (*land-use and land-cover/ LULC*) bertindak sebagai indikator vital untuk mengevaluasi transformasi spasial regional dan tekanan lingkungan. Penelitian ini bertujuan untuk mengkuantifikasi pola konversi lahan dekadal dan menilai implikasi ekologisnya di Kabupaten Malang dari tahun 2015 hingga 2025 dengan menggunakan citra Landsat dan data proyeksi di seluruh tujuh kelas LULC. Hasilnya menunjukkan ekspansi yang signifikan pada permukiman (3.592,92 ha), pertanian (6.780,84 ha), perkebunan (155,18 ha), dan badan air (5,28 ha), di samping kontraksi pada hutan (3.774,69 ha), lahan terbuka (6.214,27 ha), dan semak belukar (545,26 ha) yang didorong oleh ekspansi perkotaan dan agraria. Secara ekologis, kehilangan vegetasi ini mengancam daya dukung lingkungan (*environmental carrying capacity*) dengan merusak fungsi hidrologis dan meningkatkan risiko erosi. Konsekuensinya, temuan ini menyoroti perlunya perencanaan tata ruang yang cermat dan regulasi penggunaan lahan yang ketat untuk memastikan keberlanjutan regional.

Kata Kunci: Citra landsat, Daya dukung lingkungan, Kabupaten Malang, Penggunaan dan penutupan lahan

ABSTRACT

Land-use and land-cover (LULC) dynamics act as vital indicators for evaluating regional spatial transformations and environmental pressures. This study aims to quantify decadal land conversion patterns and assess their ecological implications in Malang Regency from 2015 to 2025 using Landsat imagery and projection data across seven LULC classes. Results indicate a significant expansion in settlements (3,592.92 ha), agriculture (6,780.84 ha), plantations (155.18 ha), and water bodies (5.28 ha), alongside a contraction in forest (3,774.69 ha), open land (6,214.27 ha), and shrubland (545.26 ha) driven by urban and agrarian expansion. Ecologically, this vegetation loss threatens environmental carrying capacity by impairing hydrological functions and elevating erosion risks. Consequently, these findings highlight the necessity for rigorous spatial planning and strict land-use regulations to ensure regional sustainability.

Keywords: Landsat imagery, Environmental carrying capacity, Malang regency, LULC

Corresponding Author : Monika Agustia, Program Studi Teknologi Tanaman Hortikultura, Jurusan Teknologi Produksi Pertanian, Politeknik Pertanian Negeri Pangkajene Kepulauan, Jalan Poros Makassar-Parepare KM. 83, Sulawesi Selatan, Email: monikagustia.08@gmail.com

Informasi artikel: diserahkan (20, 06, 2026), direvisi (27, 06, 2026), diterima (29, 06, 2026)



Introduction

Land-use and land-cover (LULC) dynamics are primary indicators for understanding the spatial transformation and environmental pressures inherent in rapidly developing regions. Malang Regency, the second-largest regency in East Java, features a diverse and heterogeneous landscape encompassing high-altitude forests, extensive agricultural lands, coastal plantations, and dense urban settlements. As the region experiences significant demographic growth and rapid economic intensification, its natural vegetation is increasingly converted into cultivated or built-up areas, particularly in zones with high infrastructural accessibility. While this development is vital for local economic activity, unregulated LULC shifts can compromise ecological balance, hydrological integrity, and overall environmental carrying capacity. Previous multitemporal analyses in Malang Raya and the wider East Java region consistently demonstrate that urbanization persistently drives the expansion of built-up land at the expense of natural vegetation cover. Consequently, this research aims to quantify the decadal LULC conversion patterns in Malang Regency from 2015 to 2025 and assess their implications for long-term environmental sustainability, providing an evidence-based foundation for improved spatial planning and mitigation strategies.

Literature Review

Land cover refers to the physical features covering the Earth's surface, which can be observed through remote sensing (Foody, G. M., 2023). Common land-cover classes include forest, settlement, paddy field, plantation, water body, open land, and shrubland. In spatial studies, land cover is used to assess environmental change, resource distribution, and development pressure in a region.

Recent studies demonstrate that multitemporal analysis is highly effective for mapping land-cover change. A Sentinel-2-based study in Malang Raya found a shift from vegetated land toward

cultivated and built-up land during 2015–2020 (Nadzirah et al., 2023). Similar findings were reported in multitemporal Landsat analyses in East Java, which showed increased built-up areas and significant changes in agricultural land and vegetation (Handoko et al., 2024). Another study in Malang City emphasized that regional development should be aligned with vegetation conservation to maintain ecosystem balance.

Outside Malang, studies in Majalengka Regency (Prayogi et al., 2024), Belitung Island (Oktavia et al., 2024), the Citarum Watershed (Nahib et al., 2026), and the Jangkak Watershed (Kadafin et al., 2026) show that Landsat-based or spatial prediction models can reveal detailed land dynamics, including increases in agricultural land, built-up areas, and vegetation changes. Thus, the study of land-cover change in Malang Regency has a strong theoretical basis and is relevant to current research trends.

Research methodology

This study uses a descriptive-quantitative approach based on secondary data. The main data are derived from Landsat image processing for 2015 and land-cover projection for 2025 in Malang Regency, the study area of which is presented in **Figure 1**.

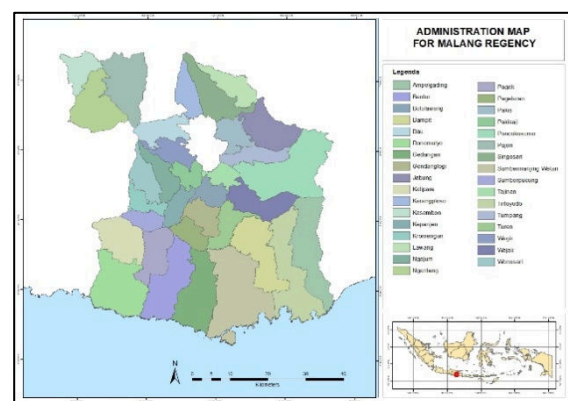


Figure 1. Administration Map for Malang Regency

Malang Regency is located between 7° 44' and 8° 26' SL and 112° 34' and 112° 57' EL. Its topography varies from lowland plains to high-elevation mountainous zones, with elevations

ranging from roughly 0 to over 3,000 meters above sea level (masl). Because of the significant quaternary volcanic activity of nearby complexes like Mount Semeru, Mount Bromo, and Mount Kawi, the region's pedological features are mostly shaped by volcanic parent materials, including fertile Andosols, Inceptisols, and Alfisols. The region is ideal for intensive agricultural production due to its complicated topography and rich soil matrix, which also provide unique microclimates and land-use potentials throughout the regency.

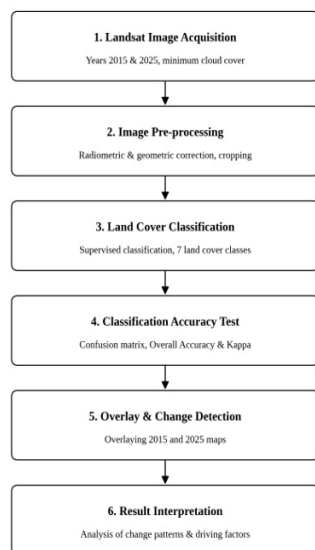


Figure 2. Map Layouting Process

As illustrated in **Figure 2**, the mapping process followed six sequential stages: Landsat image acquisition for 2015 and 2025 with minimal cloud cover, image pre-processing through radiometric and geometric correction, supervised classification into seven land-cover classes, a classification accuracy test using the confusion matrix and Kappa coefficient, spatial overlay to detect change between the two periods, and finally interpretation of the resulting change patterns and their driving factors. The land-cover classes analyzed in this classification stage include water body, forest, open land, plantation, settlement, agriculture, and shrubland.

Building on the classified maps produced through this workflow, land-cover change was analyzed using a spatial overlay technique in ArcGIS

software, in which the classified 2015 and 2025 land-cover maps were superimposed to detect changes in class boundaries and extent. This process generated the area and direction of change for each land-cover class. The analysis was conducted by comparing the area of each land-cover class between the two periods, with changes calculated in hectares and percentages, then interpreted to determine the direction of change for each class. The results were then discussed using literature from the last five years to strengthen the interpretation and improve relevance.

Results

Accuracy Assessment

To validate the reliability of the 2025 land-cover classification, an accuracy assessment was conducted using 550 independent reference points allocated proportionally across the seven land-cover classes, following the stratified sampling design of Congalton and Green (2019). Reference labels for each sampled point were determined through visual interpretation of high-resolution imagery. The resulting confusion (error) matrix is presented in **Table 1**.

Table 1. Confusion Matrix and Accuracy Assessment of the 2025 Land-Cover Classification

Class	WB	FR	OL	PT	SE	AG	SH	Tot.	UA
WB	38	0	1	0	0	11	0	50	76%
FR	0	120	2	11	0	17	0	150	80%
OL	8	0	38	1	0	2	1	50	76%
PT	0	2	0	45	0	3	0	50	90%
SE	0	0	15	1	58	1	0	75	77%
AG	0	0	0	16	0	109	0	125	87%
SH	0	4	0	1	0	0	45	50	90%
Total	46	126	56	75	58	143	46	550	
PA	83%	95%	68%	60%	100%	76%	98%		

Note: WB = Water Body; FR = Forest; OL = Open Land; PT = Plantation; SE = Settlement; AG = Agriculture; SH = Shrubland; Tot. = Row Total; UA = User's Accuracy; PA = Producer's Accuracy. Overall Accuracy = 82.4%; Kappa Coefficient = 0.787 ($n = 550$ reference points).

The classification achieved an overall accuracy of 82.4% and a Kappa Coefficient of 0.787, indicating that the level of agreement between the classified map and the reference data falls within the substantial-to-almost-perfect category, according to the interpretation scale of

Landis and Koch (1977), and is consistent with recent Kappa-based validation studies using high resolution reference imagery (Carvalho et al., 2024). Settlement, Shrubland, and Forest showed the highest producer's accuracies (100%, 97.8%, and 95.2%), while Plantation (60%) and Open Land (67.9%) were comparatively lower, mainly due to spectral confusion with Agriculture and Settlement, respectively, at Landsat's 30 m resolution. Foody (2020) emphasizes that the Kappa coefficient alone is insufficient to reveal class specific errors, which is why the full confusion matrix is also included in this study. Overall, the accuracy and Kappa values meet accepted good practice thresholds for LULC classification (Olofsson et al., 2014), supporting the reliability of the land-cover change results presented in this study.

Land-Cover Distribution (2015-2025)

The spatial distribution of land cover classes in Malang Regency for the year 2015 is shown in **Figure 3**. Based on the processing of Landsat imagery and regional reference data, the landscape is heavily dominated by forest vegetation and agricultural land uses, reflecting the regency's characteristic diverse topography and high ecological potential.

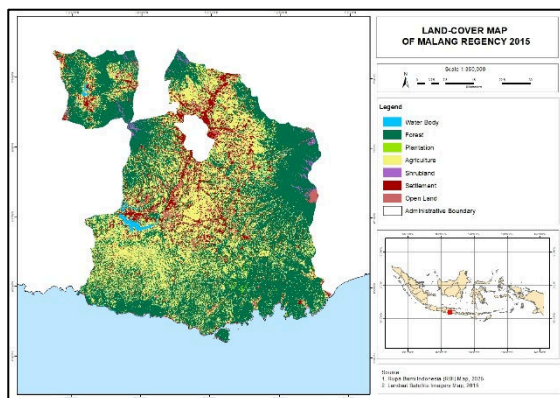


Figure 3. LULC Map for Malang Regency 2015

This spatial structure indicates that in 2015, Malang Regency maintained a strong natural and agrarian foundation, which subsequently became vulnerable to conversion pressures driven by population growth and regional development over the decadal period leading to 2025.

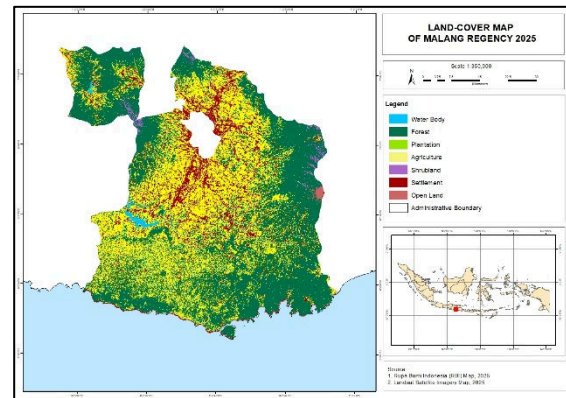


Figure 4. LULC Map for Malang Regency 2025

The spatial distribution and projection of land cover classes in Malang Regency for the year 2025 are depicted in **Figure 4**. Based on land cover projection data and spatial analysis, the regional landscape continues to be shaped by dominant forest and agricultural categories, though significant structural alterations have occurred relative to the 2015 LULC map.

This projected distribution demonstrates a clear shift toward heightened urban and agricultural intensity, reinforcing the urgent need for stringent spatial planning and proactive land-use regulations to manage environmental impacts.

Discussion

The increase in settlement area by 3,592.92 ha indicates a substantial expansion of built-up land in Malang Regency.

This trend is closely associated with population growth, rising housing demand, and the concentration of economic activities in accessible areas (Handoko et al., 2024). Badan Pusat Statistik (BPS Kabupaten Malang, 2024) through environmental data statistics also position land cover as a key environmental indicator. Thus, it obliged that settlement expansion should be treated not only as a demographic outcome but also as a spatial planning concern which requires systematic monitoring. Similar urban expansion patterns have been documented in Malang City, where built-up land

continued to increase while agricultural land declined over time, showing that

urban growth exerts persistent pressure on surrounding landscapes.

Table 2. Land Cover Change in Malang Regency, 2015-2025

Land Cover	2015		2025		Land Cover Change 2015–2025	
	Ha	%	Ha	%	Ha	%
Water Body	2,729.66	0.79	2,734.94	0.79	5.28	0.19
Forest	178,363.33	51.35	174,588.64	50.26	-3,774.69	-2.12
Open Land	7,616.34	2.19	1,402.07	0.40	-6,214.27	-81.59
Plantation	2,100.70	0.60	2,255.88	0.65	155.18	7.39
Settlement	32,324.08	9.31	35,917.00	10.34	3,592.92	11.12
Agriculture	120,927.18	34.81	127,708.02	36.77	6,780.84	5.61
Shrubland	3,282.61	0.95	2,737.35	0.79	-545.26	-16.61
TOTAL	347,343.90	100	347,343.90	100	0.00	-

Studies in other Indonesian urban-fringe areas, such as Jakarta TOD zones and the Ring Road development area of Malang City, also confirm that infrastructure growth and urbanization are strongly linked to land transformation (Rusdiono, T.P., Wibowo, A., 2025). Nadzirah et al. (2023) stated that the settlement growth observed in Malang Regency suggests increasing spatial pressure that should be managed through stricter zoning, controlled development, and land-use regulation.

The increase in agricultural land by 6,780.84 ha and plantations by 155.18 ha that shown in Table 2 indicates a shift toward more productive land use. This expansion may reflect efforts to satisfy food demand, strengthen rural livelihoods, and support local economic activity through cultivated land (Arysandi et al., 2025).

However, such growth can also occur at the expense of open land, shrubland, and even forest margins when land conversion is not properly regulated. Mandala et al. (2023) stated that land use and land cover changes often involve reallocation among productive land categories, rather than a simple replacement of natural land by urban land alone.

Forecasting studies from Majalengka and the Jangkok Watershed further show that productive land tends to expand where accessibility and

development pressure are high, unless conservation-oriented spatial controls are applied (Kadafin et al., 2026; Prayogi et al., 2024). Accordingly, agricultural intensification in Malang Regency should be paired with soil conservation, protection of critical land, and land-use zoning so that productivity gains do not undermine environmental sustainability.

The decrease in forest area by 3,774.69 ha is the most critical ecological issue identified in this study. Forests play a central role in regulating water cycles, preventing erosion, and storing carbon, so their decline can increase environmental vulnerability and reduce ecosystem services (Pramono et al., 2026). Remote sensing studies emphasize that multi-temporal land-cover analysis is essential for detecting these declines early, because satellite-based monitoring captures spatial conversion patterns more effectively than field observation alone (Nadzirah et al., 2023). In Malang Regency, ongoing forest pressure is also supported by recent forest-loss statistics from Global Forest Watch (2026), which indicate that natural forest loss remains present in the regency. Comparable research in Bengkulu (Florini et al., 2024; Tikaputra et al., 2025) and Citarum (Nahib et al., 2026) shows that deforestation and land-cover change are often linked to inconsistencies between land dynamics and spatial planning objectives. Studies from East Java likewise confirm that long-term development has significantly altered

natural landscapes (Mandala et al., 2023), reinforcing the idea that forest reduction is part of a broader regional transformation rather than an isolated local event. For that reason, the observed forest decline in Malang Regency should be viewed as a warning for watershed stability, disaster risk, and the long-term sustainability of ecosystem services.

Taken together, these land-cover transitions indicate that Malang Regency is moving from a landscape dominated by open and vegetated land toward a more intensively used pattern of settlement and production. This trajectory is consistent with findings from other Indonesian regions, where urbanization, agricultural restructuring, and infrastructure expansion are reshaping land-cover composition. Methodologically, the use of remote sensing and multitemporal classification is appropriate for documenting such changes, as recommended in the remote sensing literature (Jensen, 2021; Campbell & Wynne, 2021; Lillesand et al., 2021; Wang & Xie, 2022). In practical terms, the results support the need for stronger spatial planning enforcement, protection of remaining forest areas, and more careful agricultural land management so that economic development can proceed without compromising environmental resilience.

CONCLUSION AND SUGGESTIONS

Conclusion

During the 2015–2025 period, Malang Regency underwent significant land-use and land-cover transformations, characterized by an expansion in water bodies, plantations, settlements, and agricultural areas, alongside a contraction in forests, open lands, and shrublands. The most substantial shifts involved the notable growth of agricultural and built-up land at the expense of open spaces and natural forests. Ultimately, these spatial dynamics reflect intensive land conversion propelled by demographic pressures, economic demands, and regional development initiatives. Consequently,

implementing rigorous spatial planning and strict land-use regulations aligned with environmental carrying capacity is essential to preserve the long-term ecological sustainability of Malang Regency.

Suggestion

Malang Regency should strengthen spatial planning and land-use regulations by prioritizing areas based on environmental carrying capacity. Forests and other ecologically important areas should be protected from uncontrolled conversion, while agricultural and settlement expansion should be managed through sustainable land-use practices. Continuous GIS and remote-sensing monitoring is also recommended to support sustainable spatial planning and environmental management.

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