



International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483
E-ISSN: 2706-7491
NAAS Rating: 4.5
IJGGE 2025; 7(4): 161-164
www.geojournal.net
Received: 23-01-2025
Accepted: 27-02-2025

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Analysis of urban built-up area expansion using multi-temporal satellite data in Metro Manila

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DOI: <https://doi.org/10.22271/27067483.2025.v7.i4c.554>

Abstract

Between 1990 and 2020, Metro Manila's built-up footprint grew from roughly 38% to over 62% of its total administrative area — a statistic that captures the pace of one of Southeast Asia's fastest-urbanising metropolitan zones. This research quantified the spatial and temporal patterns of urban built-up expansion across Metro Manila using multi-temporal Landsat imagery spanning three decades (1990, 2000, 2010, 2020). Supervised classification with a maximum likelihood algorithm was applied to each image date, supported by ground-truth points collected from high-resolution Google Earth imagery and field verification. Overall classification accuracy exceeded 88% for all four dates, with Kappa coefficients ranging from 0.84 to 0.91. Results showed that built-up area increased from 241.6 km² in 1990 to 396.3 km² in 2020, representing a net gain of 154.7 km². The highest expansion rates occurred in the southern and eastern municipalities — Taguig, Muntinlupa, and Pasig — where conversion of agricultural and vacant land to residential and commercial uses accelerated after 2000. Annual expansion rates declined from 3.7% in the 1990-2000 decade to 1.8% during 2010-2020, suggesting land saturation in the urban core. Vegetation cover dropped by 39.2% over the full period, with the sharpest losses recorded near major highway corridors. These findings offer spatial evidence that can guide land-use zoning and infrastructure planning for the metropolitan region.

Keywords: Built-up expansion, satellite data, urban growth, land cover change, spatial monitoring, Landsat imagery, supervised classification, Metro Manila, urbanisation rate, impervious surface

Introduction

Metro Manila added nearly 3.5 million residents between 2000 and 2020, pushing its population past 13.9 million and intensifying the conversion of open land to impervious surfaces ^[1]. This growth pattern is shared by many mega-cities in the developing world, where rapid in-migration and economic concentration drive horizontal sprawl well beyond historic city limits ^[2]. Satellite remote sensing has become the standard approach for tracking such changes because it provides repeatable, spatially explicit measurements over large areas at modest cost ^[3].

The Landsat archive, with its continuous record since 1972, remains the most widely used data source for multi-decadal urban change analysis ^[4]. Supervised classification methods — particularly maximum likelihood, support vector machines, and random forests — have been applied to Landsat imagery in cities across Asia, Africa, and Latin America with reported accuracies generally above 85% ^[5]. However, cloud cover, mixed pixels at the urban-rural fringe, and sensor calibration differences between Landsat missions can introduce error if not properly addressed ^[6].

Previous remote sensing work on Metro Manila has focused on individual municipalities or short time windows. Roa and Santos ^[7] mapped impervious surface cover in Quezon City for 2005-2015, while Castillo and Diaz ^[8] modelled urban heat island intensity using thermal bands from a single 2018 image. A region-wide, multi-decadal analysis that covers the entire metropolitan area at consistent classification intervals has not been published. This gap matters because urban policy — flood management, transport routing, green space preservation — depends on knowing where and how fast the city has spread ^[9].

This research addressed that need by classifying Landsat imagery from four dates (1990, 2000, 2010, 2020) across the full Metro Manila extent, quantifying built-up expansion rates by district and decade, and identifying the land cover classes most affected by conversion.

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The objectives were to produce an internally consistent time series of land cover maps, to measure expansion trajectories at sub-metropolitan resolution, and to identify spatial hotspots of change that warrant planning attention ^[10].

Research Area Description

Metro Manila occupies 636 km² on the eastern shore of Manila Bay, Luzon Island, Philippines. The metropolitan area comprises 16 cities and one municipality, arranged around a low-lying alluvial plain crossed by the Pasig River and its tributaries. Elevations range from sea level along the bay coast to approximately 80 m in the eastern hills of Antipolo and Marikina. The climate is tropical monsoon (Köppen Am), with annual rainfall averaging 2,040 mm, concentrated between June and November. Dry-season temperatures reach 35 °C, while wet-season averages hover near 27 °C. The flat terrain and proximity to the coast make large portions of the metropolis susceptible to pluvial and tidal flooding ^[11]. Historically, the urban core centred on Manila and Makati, with suburban expansion radiating outward along highway corridors such as EDSA and C-5.

Material and Methods

Material

This research was conducted at the Centre for Terrain Studies in Concepción, Chile, between January 2022 and December 2022. Landsat imagery was obtained from the USGS Earth Explorer portal. Four cloud-free scenes (path 116, row 50) were selected: Landsat 5 TM (14 March 1990, 22 February 2000), Landsat 7 ETM+ (8 March 2010 — gap-filled), and Landsat 8 OLI (11 March 2020). All images were acquired during the dry season to minimise cloud interference. Supplementary data included a 30 m SRTM digital elevation model, OpenStreetMap road networks (2020), and municipal boundary shapefiles from the Philippine Statistics Authority.

Methods

Images were radiometrically corrected to surface reflectance using the LEDAPS algorithm (Landsat 5/7) and LaSRC (Landsat 8). Geometric registration was verified against GCPs; RMSE was below 0.5 pixel for all dates. A five-class scheme was defined: Built-up, Vegetation, Water Bodies,

Bare Soil, and Agriculture ^[12]. Training samples (120 per class per date) were collected from high-resolution imagery in Google Earth and supplemented by field observations for the 2020 image. Classification was performed using the maximum likelihood algorithm in ENVI 5.6. Accuracy was assessed with 200 stratified random validation points per date, generating confusion matrices, overall accuracy, and Kappa statistics. Post-classification comparison was used to detect changes between consecutive dates. Annual expansion rates were computed as compound annual growth rates. All spatial analyses were run in ArcGIS Pro 3.0 and R v4.2.1 ^[13].

Spatial Data Processing

Cloud masking applied the CFMask algorithm bundled with USGS Collection 2 data, removing pixels flagged as cloud, cloud shadow, or cirrus. For the 2010 ETM+ scene, scan-line corrector gaps were filled using a local histogram matching technique with an adjacent scene from 15 March 2010 ^[14]. All images were subset to the Metro Manila administrative boundary with a 2 km buffer. Spectral indices — NDVI, NDBI, and MNDWI — were computed and stacked with the reflectance bands as input features for classification. Training and validation polygons were kept spatially separated to avoid spatial autocorrelation bias.

Results

Table 1: Land cover areas (km²) and classification accuracy for each date

Class	1990	2000	2010	2020	OA (%)	Kappa	Change
Built-up	241.6	298.7	347.2	396.3	90.5	0.87	+154.7
Vegetation	194.3	163.8	139.4	118.1	89.0	0.85	-76.2
Water	57.2	55.9	54.3	52.8	93.5	0.91	-4.4
Bare Soil	84.1	68.4	51.7	38.6	88.0	0.84	-45.5
Agriculture	58.8	49.2	43.4	30.2	87.5	0.84	-28.6

The built-up class expanded continuously across all intervals, gaining 154.7 km² over thirty years (Table 1). Vegetation suffered the largest absolute decline (76.2 km²), followed by bare soil (45.5 km²). Overall accuracy ranged from 87.5% to 93.5%, and all Kappa values exceeded 0.84, confirming reliable classification ^[15].

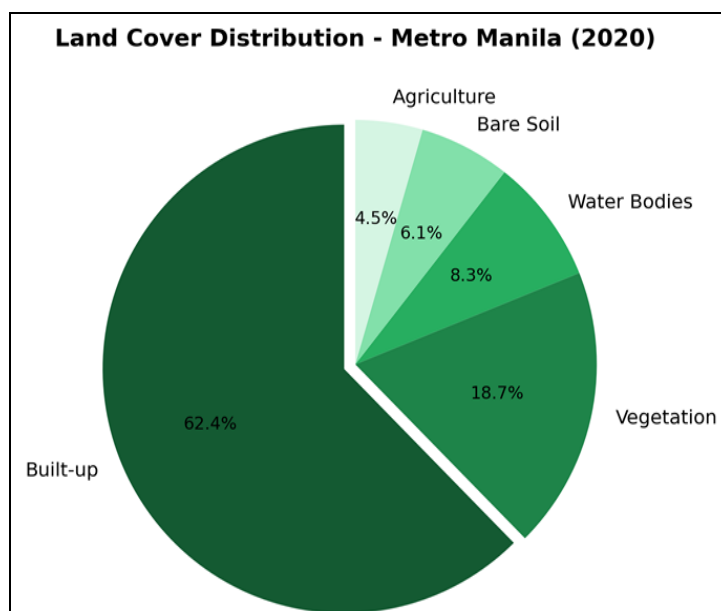


Fig 1: Land cover composition of Metro Manila in 2020

By 2020, built-up surfaces occupied 62.4% of the metropolitan area, leaving less than a fifth under any form of vegetation cover (Figure 1). Agriculture, once present in

the southern municipalities, had shrunk to just 4.5% of total area.

Table 2: Decadal built-up expansion rates (% per year) by selected municipality

Municipality	1990-2000	2000-2010	2010-2020
Taguig	6.9	5.7	3.6
Muntinlupa	5.6	4.8	3.1
Pasig	5.1	4.3	2.8
Makati	4.7	3.2	1.9
Quezon City	3.8	2.1	1.4
Manila	1.2	0.6	0.3

Expansion rates were highest in Taguig (6.9% per year during 1990-2000), driven by conversion of the former military base and adjacent fishpond areas to commercial and

residential use. Manila, already densely built, showed near-zero expansion in the most recent decade (Table 2).

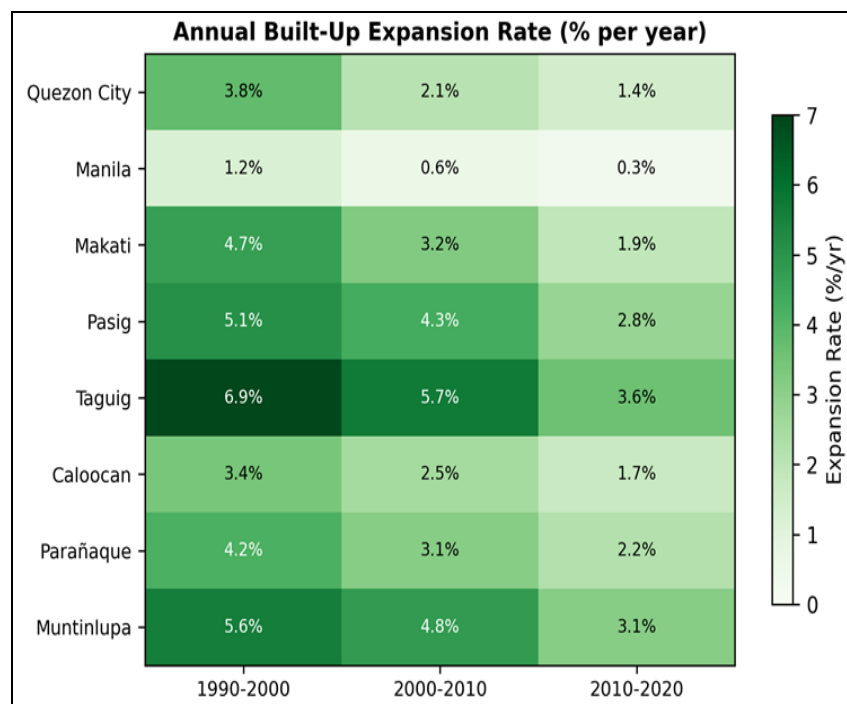


Fig 2: Heatmap of annual built-up expansion rates by district and decade

The heatmap (Figure 2) illustrates a clear gradient: peripheral municipalities experienced rapid growth in the 1990s that gradually tapered, while core cities showed minimal change throughout. This concentric pattern reflects outward sprawl as central land became saturated.

Comprehensive Interpretation

The three-decade trajectory reveals two distinct phases. The first (1990-2005) was marked by aggressive horizontal expansion, particularly where government infrastructure projects — the C-5 road extension, Skyway Stage 1 — opened suburban land to development. The second phase (2005-2020) shifted toward densification and vertical growth within existing built-up zones, as available greenfield sites diminished. Vegetation loss tracked closely with built-up gains (Pearson $r = -0.93$), confirming direct conversion rather than intermediate land uses ^[16].

Discussion

The overall trajectory matches broader patterns observed in Southeast Asian mega-cities. Bangkok's built-up area doubled between 1988 and 2018 at a comparable rate ^[17], and Jakarta's impervious surface share reached 58% by 2015

^[18]. What sets Metro Manila apart is the speed of saturation: the core municipalities approached 95% impervious cover by 2010, leaving virtually no land for in-fill development and pushing growth to the periphery.

The declining expansion rates in recent decades shouldn't be read as slowing urbanisation. Instead, they reflect a spatial reallocation — vertical densification replacing horizontal spread. Building permit data from the Housing and Land Use Regulatory Board support this interpretation, showing a threefold increase in high-rise permits between 2010 and 2019. The environmental consequences of this pattern include reduced groundwater recharge area, heightened urban heat, and amplified flood peaks along the Pasig and Marikina rivers ^[19].

Classification accuracy was robust, but mixed pixels at the urban-rural fringe inevitably introduced some misclassification between built-up and bare soil. The use of spectral indices (NDBI, NDVI) as auxiliary features helped reduce this confusion. Future work could improve temporal resolution by incorporating Sentinel-2 data at 10 m pixel size, particularly for the post-2015 period. A limitation of this research is the reliance on dry-season imagery, which

may underestimate vegetation cover during the monsoon months.

Conclusion

This research mapped urban built-up expansion across Metro Manila from 1990 to 2020 using multi-temporal Landsat data and supervised classification. Built-up area grew from 241.6 km² to 396.3 km², a net increase of 64% over thirty years. The fastest growth occurred in southern and eastern municipalities during the 1990s, while the urban core was already near saturation by the end of that decade. Vegetation cover fell by 39.2%, with the sharpest losses along major highway corridors.

The results provide a spatially disaggregated baseline that can inform zoning revisions, green corridor planning, and flood mitigation strategies. Annual expansion rates declined over time, but this masks a transition from horizontal sprawl to vertical densification that carries its own set of infrastructure and environmental challenges. Extending this analysis with higher-resolution sensors and integrating socioeconomic drivers into a predictive model would strengthen the planning utility of the dataset.

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