KFUPM
Journal of Undergraduate Research International

Diamond Open Access

Article
Environmental Science and Engineering/Earth Sciences

Detection of Urban Changes in Mumbai, Jakarta, Hong Kong, Dhaka, and Beijing

Latifa Alhabeeb[1] and Muhammad Bilal [1,2]*

Cite https://doi.org/10.64589/juri/209736

Submitted: June 04, 2025 Revised: July 28, 2025 Accepted: August 20, 2025

ABSTRACT

This study presents a multi-city assessment of urban expansion across five Asian megacities—Mumbai, Jakarta, Hong Kong, Dhaka, and Beijing—between 2014 and 2024. Using Landsat 8 and 9 surface reflectance imagery, four spectral indices—Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Built-up Index (BUI), and Index-Based Built-up Index (IBI)—were computed within Google Earth Engine (GEE). A harmonized classification framework was applied to detect annual transitions between built-up and non-built-up areas. Urban dynamics were quantified through six key metrics: built-up area, non-built-up area, annual gain, annual loss, total change, and net transition. Results reveal heterogeneous urbanization trajectories. Jakarta exhibited the most substantial net increase (~22%), reflecting rapid sprawl, while Hong Kong showed compact but significant growth (~14%), consistent with vertical densification. Dhaka experienced rapid but spatially inconsistent expansion, with peripheral encroachment and inner-city restructuring. Beijing displayed stable, regulated growth shaped by planning policies, whereas Mumbai exhibited a unique decline of ~9% in built-up areas, suggesting a shift toward vegetated land cover. These findings highlight how harmonized remote sensing indices can capture nuanced urban patterns across diverse ecological and governance contexts. The study contributes practical insights for sustainable urban planning and provides a reproducible, low-cost framework for long-term urban monitoring in data-scarce regions..

Keywords: urban growth, remote sensing, NDVI, NDBI, built-up index, megacities

1. INTRODUCTION

Urban expansion is one of the defining processes of the 21st century. Globally, more than half the population resides in urban areas, and by 2050, this figure is projected to approach 70% [1,2]. Asian megacities, particularly those situated in coastal and floodplain areas, are undergoing an unprecedented transformation due to rapid population growth, economic dynamism, and climate-related pressures, including flooding and sea-level rise [3–5]. These processes reshape spatial structures, intensify land-use conflicts, and exacerbate sustainability challenges.

Among Asian cities, Mumbai, Jakarta, Hong Kong, Dhaka, and Beijing exemplify contrasting yet comparable cases.

- *Mumbai* demonstrates unregulated sprawl driven by informal settlements and constrained land availability.
- *Jakarta* is a transitional city where informal expansion interacts with state-led relocation and reclamation projects, compounded by subsidence and flooding.
- *Hong Kong* reflects compact vertical growth shaped by terrain and policies prioritizing density and green preservation.
- *Dhaka* epitomizes hyper-urbanization in a deltaic environment, where informal settlements expand into wetlands and floodplains.
- *Beijing* represents regulated peri-urban expansion with strong planning interventions under the "Beautiful China" and Jing-Jin-Ji strategies.

Together, these cities illustrate diverse governance, ecological, and socioeconomic contexts, offering a comparative lens into Asia's urban transformation.

Satellite-based remote sensing has emerged as a reliable and cost-effective method for detecting changes in urban land-cover change. Spectral indices provide objective classification of vegetation and built-up areas across time and space. The four indices used in this study—NDVI, NDBI, BUI, and IBI—are widely validated for distinguishing urban from non-urban surfaces.

Most existing studies, however, focus on single cities **or** short-term analyses**.** Few have harmonized thresholds across multiple cities and applied consistent methodologies to allow meaningful cross-comparisons. This study addresses this gap by implementing a standardized multi-index, multi-city approach across five megacities for the decade 2014–2024. This study aims to: (i) Quantify annual changes in built-up and non-built-up land across five Asian megacities. (ii) Compare multi-index trajectories across diverse ecological and governance contexts. (iii) Identify gains, losses, and net transitions in the built-up area. (iv) Evaluate index performance in detecting urban changes under varied urban landscapes. (v) Provide transferable insights for sustainable urban planning and monitoring.

2. METHODOLOGY

2.1. Study Areas. Figure 1 shows the AOIs for Mumbai, Jakarta, Hong Kong, Dhaka, and Beijing. These five cities were chosen for their contrasting urbanization pressures: coastal reclamation (Mumbai, Jakarta, Hong Kong), floodplain expansion (Dhaka), and planned inland development (Beijing).

2.2. Data Sources. Annual Landsat 8 OLI/TIRS and Landsat 9 OLI/TIRS surface reflectance imagery (30 m resolution) were used for the period 2014–2024[6–8]. Landsat data were accessed through the Google Earth Engine (GEE) platform, ensuring consistency and free availability.

- Temporal selection: January–March median composites were generated for each year to minimize phenological variations, reduce seasonal bias, and avoid monsoon effects (significant in tropical cities).
- Spatial selection: Administrative boundaries were digitized for each city to define Areas of Interest (AOIs).
- Projection: All datasets were reprojected to WGS84 for global consistency.

This section outlines the satellite datasets, index-based classification techniques, and annual urban change-detection methods used in this study, which employed a harmonized remote sensing framework to evaluate urban expansion in five major Asian cities (Mumbai, Jakarta, Hong Kong, Dhaka, and Beijing) between 2014 and 2024.

2.3. Spectral Indices. Four indices were computed using standard band equations:

1. ***Normalized Difference Vegetation Index (NDVI):***

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \tag{1}$$

Initially introduced by Rouse et al. (1974)[9], NDVI highlights vegetated vs. non-vegetated land.

2. ***Normalized Difference Built-up Index (NDBI):***

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)} \tag{2}$$

Proposed by Zha et al. (2003)[10], NDBI enhances built-up detection.

3. ***Built-up Index (BUI):***

$$BUI = NDBI - NDVI \tag{3}$$

Combines vegetation and built-up indices for clearer separation[11].

4. ***Index-Based Built-up Index (IBI):***

$$IBI = \frac{NDBI - (NDVI - MNDWI)}{NDBI + (NDVI + MNDWI)} \tag{4}$$

Where:

$$MNDWI = \frac{(Green - SWIR)}{(Green + SWIR)} \tag{5}$$

Introduced by Xu (2008)[12], IBI incorporates water index information to reduce misclassification in mixed urban environments.

2.4. Thresholding and Classification. For each city, visually calibrated thresholds were applied consistently across all years to classify pixels into built-up and non-built-up. These thresholds (Table 1) accounted for environmental differences, such as stricter NDVI thresholds in vegetated cities (e.g., Hong Kong, Dhaka) compared to relaxed ones in arid Beijing.

3. RESULTS AND DISCUSSION

This section presents the spatial and temporal dynamics of urban changes in the five cities, analyzed using NDVI, NDBI, BUI, and IBI indices.

3.1. Urban Index Maps.

3.1.1. Mumbai. Figure 2 illustrates Mumbai's land-cover classifications using RGB, NDVI, NDBI, BUI, and IBI. Built-up surfaces expanded northward and eastward, with visible growth along reclaimed coastal zones and transport corridors. However, compared with other cities, Mumbai exhibited intermittent reversals where vegetated land appeared to recover.

- NDVI emphasized vegetation loss across peri-urban and coastal zones, with sharp declines between 2016 and 2020.
- NDBI effectively captured rooftops and dense built-up areas, especially in northern suburbs. Major expansion was observed in 2015, 2018, and 2022.
- BUI confirmed steady intensification across central and northeastern districts.
- IBI provided balanced detection, reducing misclassification in shadowed areas.

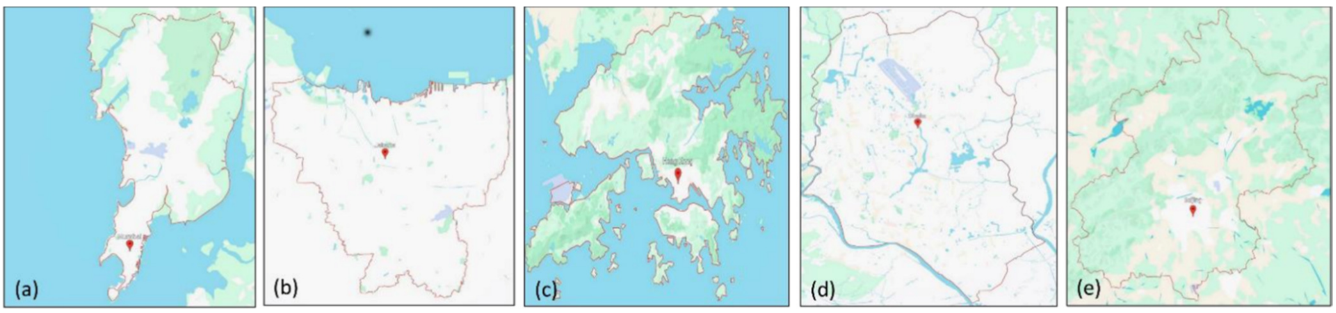

Figure 1. Locations and AOIs of the five study cities.

Table 1. *Threshold values for NDVI, NDBI, BUI, and IBI (2014–2024).*

Index	Mumbai (2014–2024)	Jakarta (2014–2024)	Hong Kong (2014–2024)	Dhaka (2014–2024)	Beijing (2014–2024)
NDVI	0.25 (2014), 0.35 (2024)	0.30 (2014), 0.30 (2024)	0.30 (2014), 0.30 (2024)	0.30 (2014), 0.30 (2024)	0.20 (2014), 0.20 (2024)
NDBI	0.00 (2014), 0.05 (2024)	0.05 (2014), 0.07 (2024)	0.00 (2014), 0.00 (2024)	0.00 (2014), 0.00 (2024)	0.00 (2014), 0.00 (2024)
BUI	−0.25 (2014), −0.20 (2024)	−0.22 (2014), −0.20 (2024)	−0.25 (2014), −0.20 (2024)	−0.20 (2014), −0.20 (2024)	−0.30 (2014), −0.30 (2024)
IBI	−0.60 (2014), −0.55 (2024)	−0.58 (2014), −0.55 (2024)	−0.50 (2014), −0.65 (2024)	−0.70 (2014), −0.70 (2024)	−0.50 (2014), −0.50 (2024)

Year-to-year differences reveal alternating gains and losses. Periods such as 2015–2016 and 2017–2018 show moderate built-up gains, while 2016–2017 and 2018–2019 exhibit losses or vegetation recovery. After 2020, Mumbai's transitions show a bias toward net los**s**, reinforcing the overall decline noted earlier. Despite episodic construction surges, Mumbai displayed an overall 9% decline in net built-up area by 2023. This reversal may be attributed to coastal protection programs, mangrove restoration efforts, and enhanced environmental enforcement.

3.1.2. Jakarta. As shown in Figure 3, Jakarta underwent extensive outward growth during the decade. Built-up expansion was especially prominent in eastern and southern districts, while vegetation fragmentation occurred in central and northern areas.

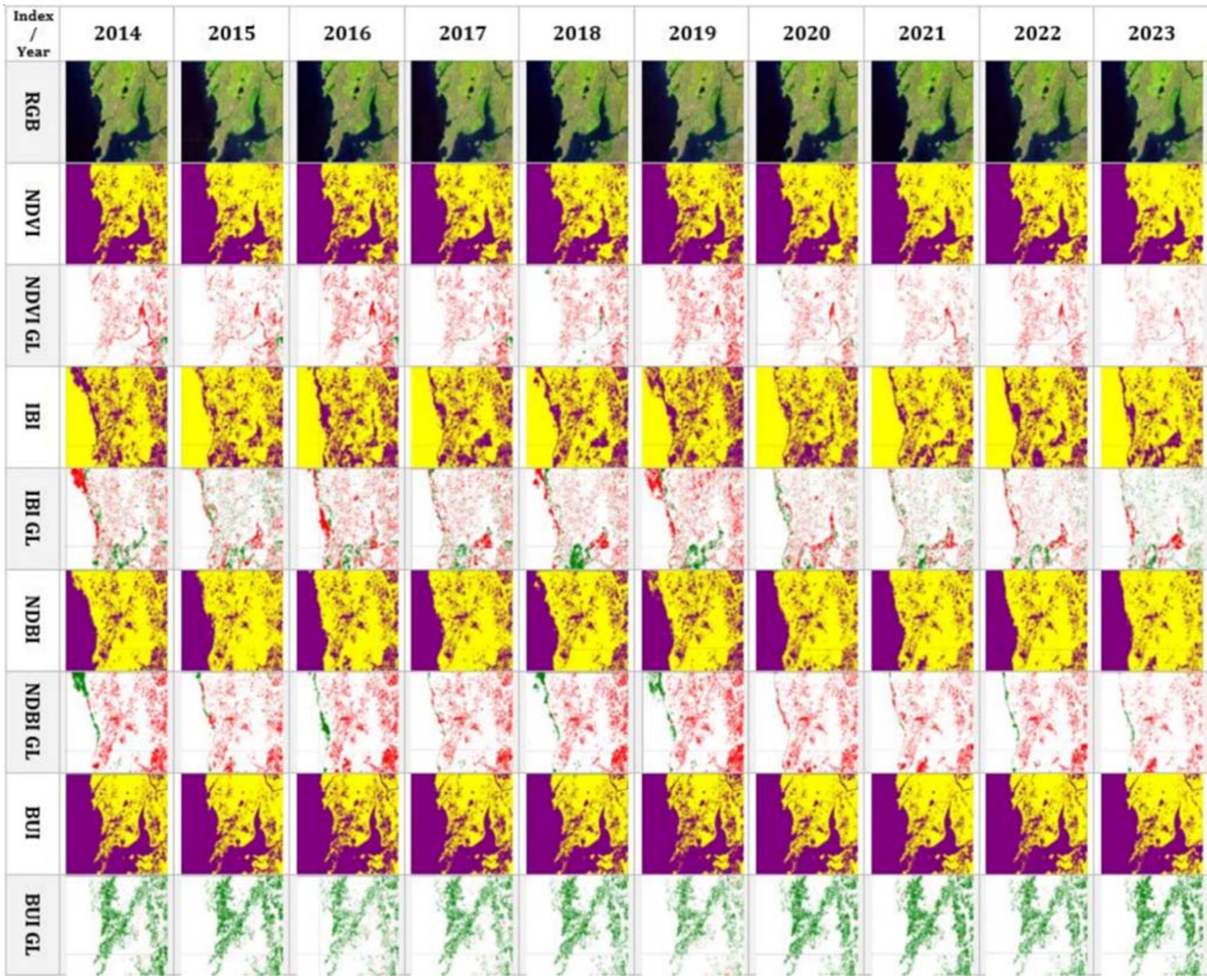

Figure 2. Annual classification and gain/loss maps for Mumbai (2014–2023). Built-up areas are shown in purple and non-built-up areas in yellow. Green indicates new urban development (gain), while red highlights areas of built-up land loss.

- NDVI revealed steady vegetation loss after 2017, particularly in peri-urban zones.
- NDBI captured linear growth along industrial corridors and highways.
- BUI highlighted concentric outward growth around the core.
- IBI depicted densification along the urban fringe.

The results show consistent positive transitions, particularly during the periods of 2015–2016, 2018–2019, and 2022–2023. Negative transitions were minimal and scattered, indicating a strong net expansion trajectory. Jakarta recorded the most significant net increase (~22%) in built-up area among the five cities. Land subsidence and flood-prone conditions may have influenced land-use restrictions in the north, redirecting expansion southward.

3.1.3. Hong Kong. Figure 4 shows Hong Kong's compact but intensive urban development. Expansion was concentrated in reclaimed zones (West Kowloon, Tseung Kwan O, and parts of Lantau).

- NDVI detected gradual vegetation fragmentation along urban fringes.
- NDBI revealed consistent intensification in Kowloon and Hong Kong Island.
- BUI confirmed clustering around transit hubs and public housing estates.
- IBI effectively detected vertical and infill development, reflecting Hong Kong's densification strategy.

Hong Kong shows smaller but steady positive bars in most years, reflecting controlled densification and reclamation. Occasional minor negative values (e.g., 2016–2017) may represent temporary redevelopment or vegetation misclassification. Hong Kong exhibited a 14% net gain in built-up land, primarily through vertical development and reclamation, consistent with transit-oriented planning.

3.1.4. Dhaka. Figure 5 depicts Dhaka's rapid but inconsistent expansion. While built-up areas increased across peri-urban zones, the core displayed cycles of redevelopment.

- NDVI highlighted consistent vegetation loss after 2016.
- NDBI revealed strong expansion along northern and eastern corridors.
- BUI indicated outward sprawl, consuming agricultural land.

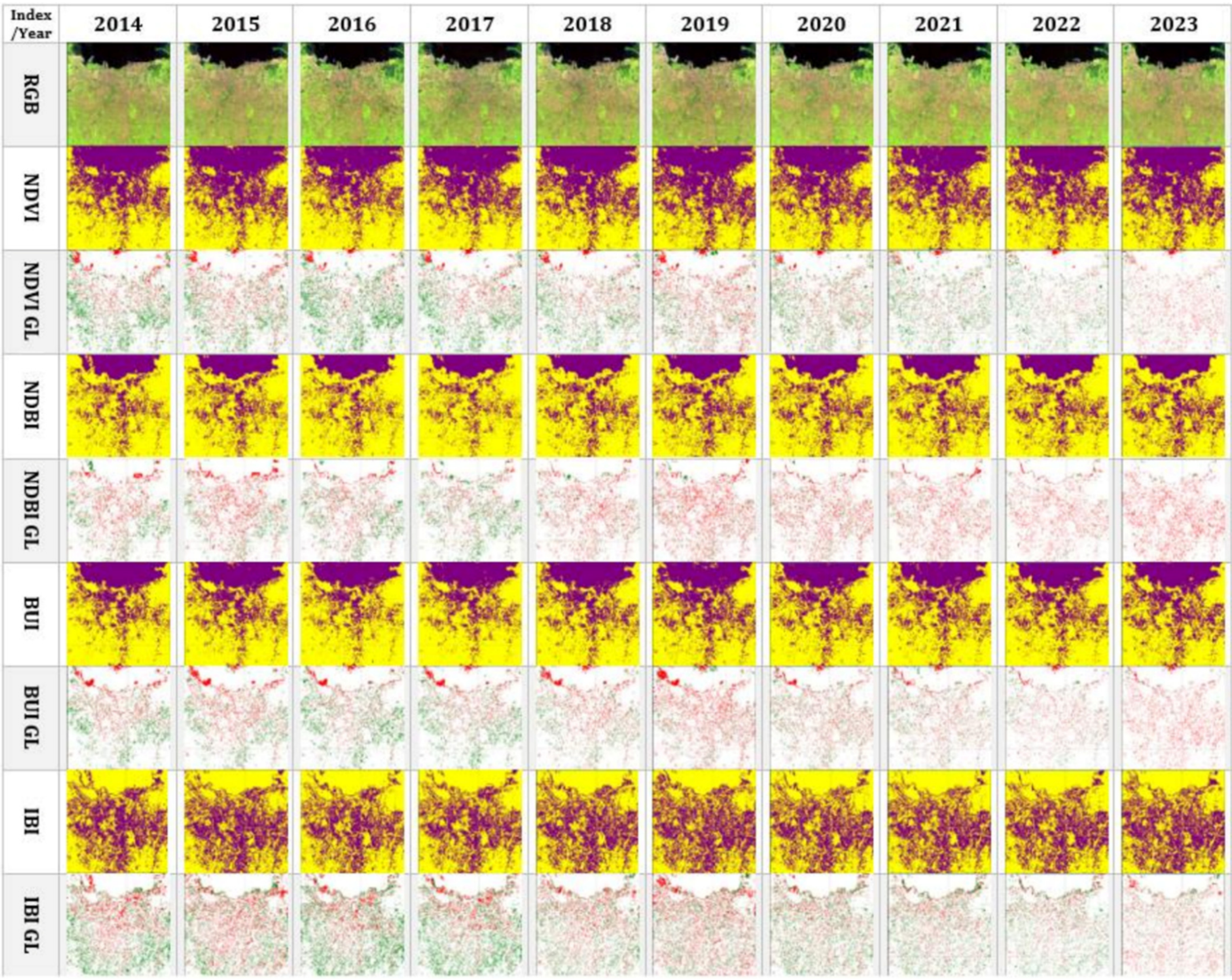

Figure 3. Annual classification and gain/loss maps for Jakarta (2014–2023). Built-up areas are shown in purple and non-built-up areas in yellow. Green indicates new urban development (gain), while red highlights areas of built-up land loss.

- IBI emphasized saturation within the urban core, particularly near transport corridors.

Dhaka's yearly transitions were volatile. Gains were evident in 2014–2017 and 2018–2020, but sharp negative bars occurred after 2020, suggesting redevelopment phases, seasonal floodplain effects, or index misclassification. Dhaka's expansion was rapid but unstable. Built-up growth was offset by localized redevelopment and misclassification during flooding seasons. Overall, the city demonstrated net positive growth, though less consistent than Jakarta or Hong Kong.

3.1.5. Beijing. Figure 6 highlights Beijing's structured outward growth. Expansion occurred primarily in suburban districts such as Tongzhou, Shunyi, and Fangshan.

- NDVI indicated gradual vegetation loss in peri-urban zones, offset by greening campaigns (e.g., afforestation).
- NDBI captured industrial and residential developments in the southern and eastern districts.
- BUI identified suburban growth along expressways and rail corridors.
- IBI emphasized densification of older urban zones (e.g., Haidian, Chaoyang).

Beijing's transitions were mostly positive until 2020, reflecting suburban expansion. Bars after 2021 show smaller or negative changes, aligning with policies promoting ecological restoration and stabilization of peri-urban growth. Beijing exhibited steady, regulated growth, consistent with its polycentric planning model and "Beautiful China" ecological policies. Unlike Jakarta or Dhaka, expansion was tightly controlled and integrated with transport planning.

3.2. Consolidated Trends, Comparative Analysis, and Limitations.

3.2.1. Mumbai. The consolidated charts for Mumbai (Figure 7) highlight a net decline in built-up area across NDVI, NDBI, BUI, and IBI.

- Built-up area: NDVI and BUI show a gradual reduction after 2018, while NDBI fluctuates, capturing temporary construction cycles.
- Non-built-up area: NDVI indicates steady vegetation recovery, particularly in coastal and wetland zones.

Figure 4. Annual classification and gain/loss maps for Hong Kong (2014–2023). Built-up areas are shown in purple and non-built-up areas in yellow. Green indicates new urban development (gain), while red highlights areas of built-up land loss.

- Gain/loss: Small gains in 2015–2016 were outweighed by consistent losses after 2020.

Mumbai is the only city in this study to show a long-term negative trajectory, possibly due to stricter coastal zone regulations, mangrove restoration, and reclassification of semi-urban land. This makes it a unique case among Asian megacities, where most are expanding.

3.2.2. Jakarta. The consolidated trends for Jakarta (Figure 13) confirm it as the fastest-growing city in the dataset.

- Built-up area: All four indices show strong upward growth, with NDBI and BUI capturing rapid sprawl along the eastern and southern peripheries.
- Non-built-up area: NDVI reveals progressive vegetation decline, particularly in agricultural zones converted to housing or industry.
- Gain/loss: Peaks in 2018–2019 and 2022–2023 indicate construction booms linked to large-scale housing projects.

Jakarta's gains far outweigh its losses. Despite flood risks and land subsidence, the city is expanding rapidly into peri-urban land, underscoring the challenges of balancing growth with environmental vulnerability.

Hong Kong

Hong Kong's consolidated results (Figure 9) reveal a steady upward trajectory in built-up area despite limited land availability.

- Built-up area: Gains are consistent across indices, strongest in IBI (vertical redevelopment and infill).
- Non-built-up area: Declined steadily, reflecting reclamation and loss of green belts in suburban districts.
- Gain/loss: Positive gains dominate most years; losses are minimal and largely transitional.

Hong Kong's growth model is compact and vertical, enabled by reclamation projects and redevelopment of high-density zones. The city shows one of the most stable positive trends.

3.2.3. Dhaka. Dhaka's consolidated charts (Figure 10) highlight its volatile and unstable urban growth pattern.

- Built-up area: Increased during 2014–2019, peaking around 2020, then declined slightly in subsequent years.

Figure 5. Annual classification and gain/loss maps for Dhaka (2014–2023). Built-up areas are shown in purple and non-built-up areas in yellow. Green indicates new urban development (gain), while red highlights areas of built-up land loss.

- Non-built-up area: NDVI shows substantial recovery after 2020, possibly due to seasonal flooding or re-greening.
- Gain/loss: Gains were large in 2016–2018, but sharp losses in 2021–2023 suggest redevelopment cycles or classification challenges in floodplains.

Dhaka exemplifies the instability of unregulated urbanization in flood-prone environments. Although net growth was positive, the magnitude of losses in later years undermines long-term sustainability.

3.2.4. Beijing. Beijing's consolidated results (Figure 11) confirm steady, regulated expansion.

- Built-up area: Grew consistently across all indices until 2020, then stabilized.
- Non-built-up area: Declined gradually, but NDVI shows partial recovery after 2021 due to afforestation.
- Gain/loss: Peaks in 2016–2018 reflect major suburban expansion; subsequent years show balanced gains and losses, aligning with policy-driven stabilization.

Beijing's growth is controlled and polycentric, guided by planning frameworks such as the Jing-Jin-Ji regional integration strategy. Unlike Jakarta or Dhaka, Beijing demonstrates long-term regulation of urban form.

3.3. Comparative Analysis. Comparing across all five cities revealed that:

- Rapid Expansion: Jakarta showed the strongest outward growth (~22% increase), driven by housing and industrial corridors.
- Compact Growth: Hong Kong displayed controlled densification (~14% increase), relying on reclamation and vertical redevelopment.
- Unstable Growth: Dhaka recorded high variability, with periods of strong gains followed by significant losses, reflecting its unregulated expansion in a flood-prone delta.
- Regulated Expansion: Beijing grew steadily, reflecting central planning, then stabilized under ecological and decentralization policies.

Figure 6. Annual classification and gain/loss maps for Beijing (2014–2023). Built-up areas are shown in purple and non-built-up areas in yellow. Green indicates new urban development (gain), while red highlights areas of built-up land loss.

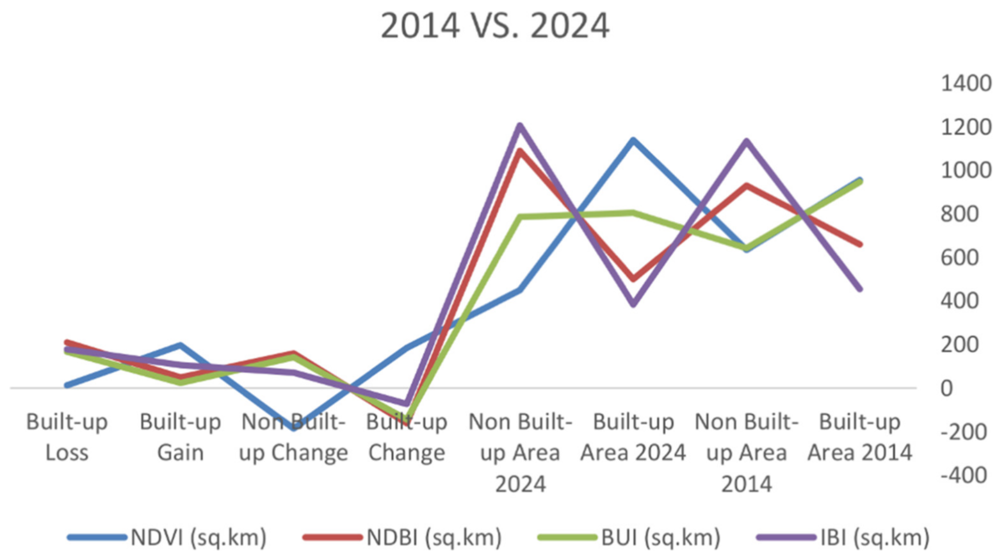

Figure 7. Consolidated charts of built-up and non-built-up trends, gains, and losses in Mumbai (2014–2023).

- Unique Decline: Mumbai stood out as the only city with a net decline (~9%) in built-up area, likely due to environmental restoration and stricter regulations.

These findings underscore the influence of policy frameworks, ecological contexts, and governance capacity on urban growth patterns in Asia.

3.4. Methodological Constraints and Limitations.

Despite rigorous processing, several limitations must be acknowledged:

1. Threshold Sensitivity: Threshold calibration was manual and visually guided. While consistent across years, subjective thresholds may misclassify mixed pixels, especially in transitional zones (e.g., urban-vegetation interfaces in Dhaka or Hong Kong).
2. Vegetation Interference: NDVI misclassified green roofs, wetlands, and peri-urban greenery as non-urban in highly vegetated cities (Hong Kong, Dhaka). Conversely, sparse vegetation in Mumbai occasionally confused NDVI into labeling built-up land as "green."
3. Temporal Variability: Using annual composites reduced seasonality but may not fully capture intra-annual fluctuations (e.g., flood-related land-use changes in Dhaka, construction pauses in Mumbai).
4. Spatial Resolution: Landsat's 30 m resolution smooths fine-scale urban features (narrow streets, small plots). While suitable for regional comparisons, it underrepresents micro-scale redevelopment.
5. Index Behavior: Each index had distinct strengths and weaknesses:
   - NDBI was effective for dense urban cores but underestimated in arid zones (Mumbai).
   - NDVI was unsuitable for heavily vegetated cities.
   - BUI provided balanced detection but smoothed variations.

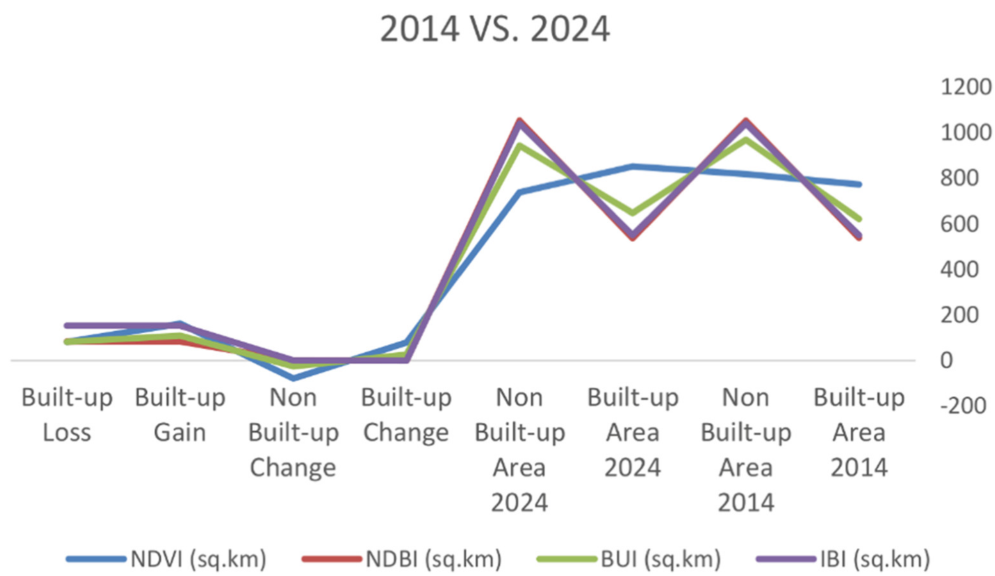

Figure 8. Consolidated charts of built-up and non-built-up trends, gains, and losses in Jakarta (2014–2023).

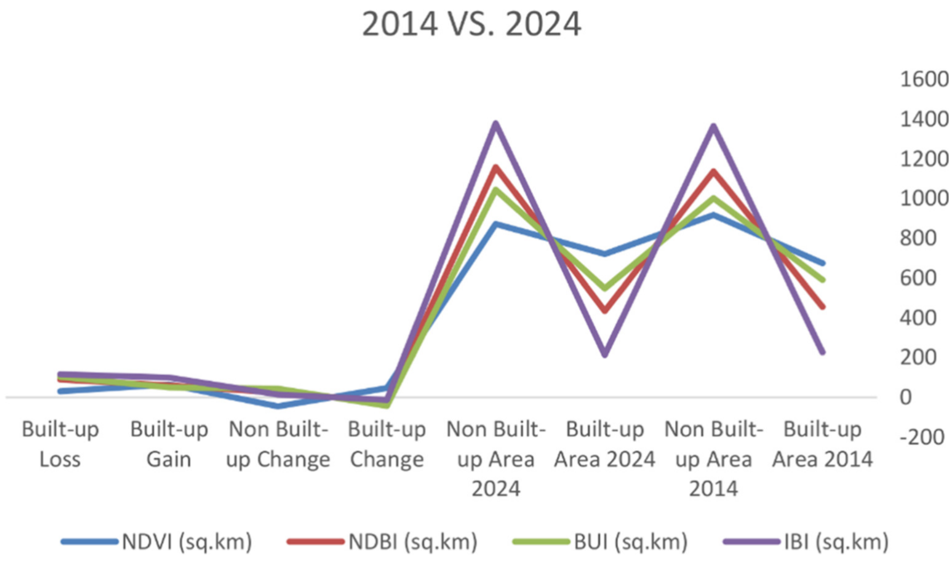

Figure 9. Consolidated charts of built-up and non-built-up trends, gains, and losses in Hong Kong (2014–2023).

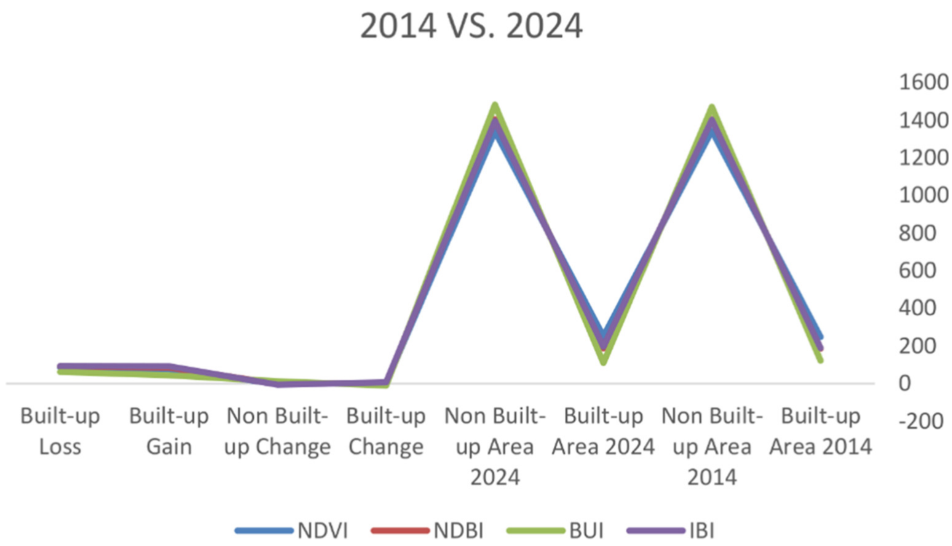

Figure 10. Consolidated charts of built-up and non-built-up trends, gains, and losses in Dhaka (2014–2023).

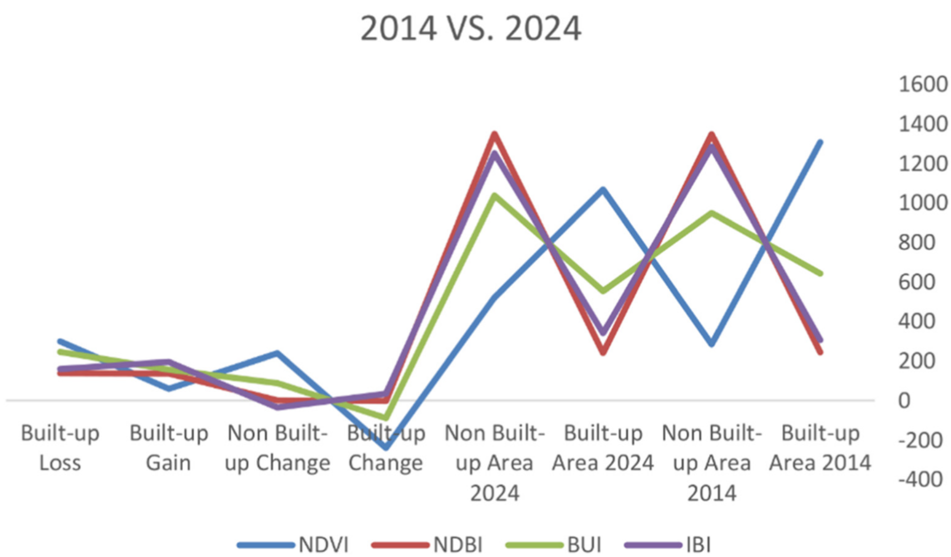

Figure 11. Consolidated charts of built-up and non-built-up trends, gains, and losses in Beijing (2014–2023)

- IBI captured compact/vertical growth but was overly sensitive in redevelopment phases (Seoul, Dhaka).

6. Validation Limitations: No ground-truth accuracy assessment was performed due to data availability. Visual verification against RGB composites ensured general validity but lacked quantitative accuracy metrics.

The harmonized multi-index framework enabled cross-city comparability, but improvements could include higher-resolution imagery, automated thresholding, or machine learning classifiers.

4. CONCLUSIONS

This study investigated urban growth dynamics in five Asian megacities—Mumbai, Jakarta, Hong Kong, Dhaka, and Beijing—over the period 2014–2024 using Landsat 8/9 imagery and four widely used remote sensing indices (NDVI, NDBI, BUI, IBI). By applying harmonized thresholds across all cities, we quantified annual changes in built-up and non-built-up areas, examined year-to-year transitions, and consolidated long-term growth trajectories. Key findings include: (i) Jakarta recorded the most rapid and sustained expansion (~22% net increase), reflecting unregulated sprawl and suburbanization, especially in eastern and southern corridors. (ii) Hong Kong showed compact, vertical growth (~14% increase), consistent with reclamation projects and transit-oriented redevelopment. (iii) Dhaka experienced volatile expansion, with strong early growth followed by significant losses after 2020, highlighting the instability of unregulated growth in flood-prone regions. (iv) Beijing displayed steady, regulated expansion until 2020, then stabilized due to ecological restoration and decentralization policies. (v) Mumbai was unique in showing a net decline (~9% reduction), likely influenced by coastal conservation policies, mangrove restoration, and land-use reclassification. The comparative results confirm that policy frameworks and governance strongly influence urban outcomes. Cities with strong planning regimes (Beijing, Hong Kong) experienced controlled growth, while those with weaker regulation (Jakarta, Dhaka) faced rapid and unstable sprawl. The ecological context also mattered: floodplains (Dhaka, Jakarta) exhibited volatile patterns, while arid Mumbai reflected unique reversals linked to conservation efforts. A multi-index approach was essential for reducing bias. NDVI underperformed in green cities, while NDBI performed better in arid ones, whereas BUI and IBI provided a more balanced classification.

The harmonized multi-index framework demonstrated that medium-resolution Landsat imagery, processed on GEE, can provide replicable and cost-effective monitoring of megacities across diverse contexts. This approach is particularly valuable for developing regions where ground data are scarce.

Overall, this study shows that Asian megacities exhibit diverse, context-driven urban trajectories and that remote sensing indices can capture both the pace and direction of these changes. These insights are crucial for urban planners and policymakers seeking to strike a balance between growth and environmental sustainability.

5. RECOMMENDATIONS

5.1. Recommendations for Future Work.

- Integrating higher-resolution imagery (e.g., Sentinel-2, PlanetScope) for improved detection of fine-scale changes.
- Automating thresholding using machine learning or time-series classification models.
- Incorporating socio-economic and policy datasets to strengthen interpretation of remote sensing results.
- Extending comparative frameworks to additional cities for a broader regional perspective.

AFFILIATIONS AND AUTHOR DETAILS

Undergraduate Author

Latifa Alhabeeb – *Architecture and City Design Department, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia;* 0009-0009-6967-6491
Email: s202243320@kfupm.edu.sa

Corresponding Author

Muhammad Bilal – *Research Mentor, Architecture and City Design Department, College of Design and Built Environment, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia; Center for Aviation and Space Exploration,;* 0000-0003-1022-3999
Email: muhammad.bilal@kfupm.edu.sa

ACKNOWLEDGEMENTS

This report was completed as part of an undergraduate program in the Department of Architecture and City Design at King Fahd University of Petroleum and Minerals (KFUPM). The author thanks the faculty advisors and the JURI editorial team for their valuable guidance and support throughout the project.

The author also acknowledges the use of AI-based tools to improve the clarity and structure of the manuscript's English. The analysis, results, and interpretations remain entirely the original work of the student researcher.

REFERENCES

(1) Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Seto, K. C. (2013). *Urbanization, biodiversity and ecosystem services: Challenges and opportunities.* Springer. (See chapter on urban expansion and land-use conflicts). https://doi.org/10.1007/978-94-007-7088-1

(2) Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences, 109*(40), 16083–16088. https://doi.org/10.1073/pnas.1211658109

(3) Becker, M., Seeger, K., Paszkowski, A., Loebl, M., Pham, T. T. H., Weerts, A. H., Minderhoud, P. S. J. (2024). Coastal flooding in Asian megadeltas: Recent advances, persistent challenges, and call for actions amidst local and global changes. *Reviews of Geophysics*, https://doi.org/10.1029/2024RG000846

(4) Chan, F. K. S., Chuah, C. J., & Gao, X. (2014). Impacts of climate change: Challenges of flooding in coastal East Asia. In M. Beeson & S. Hameiri (Eds.), *Routledge Handbook of Asian Regionalism* (pp. 1–20). Routledge. https://eprints.whiterose.ac.uk/id/eprint/81151/

(5) Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise

and coastal flooding: A global assessment. *PLoS ONE, 10*(3), e0118571. https://doi.org/10.1371/journal.pone.0118571

(6) Bilal, M., Nazeer, M., Nichol, J.E., Bleiweiss, M.P., Qiu, Z., Jäkel, E., Campbell, J.R., Atique, L., Huang, X., Lolli, S., 2019. A Simplified and Robust Surface Reflectance Estimation Method (SREM) for Use over Diverse Land Surfaces Using Multi-Sensor Data. Remote Sensing 11.

(7) Nazeer, M., Ilori, C.O., Bilal, M., Nichol, J.E., Wu, W., Qiu, Z., Gayene, B.K., 2021. Evaluation of atmospheric correction methods for low to high resolutions satellite remote sensing data. Atmospheric Research 249.

(8) Vermote, E., Justice, C., Claverie, M., Franch, B., 2016. Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product. Remote Sens Environ Volume 185, 46–56.

(9) Huang, S., Tang, L., Hupy, J.P. et al. A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *J. For. Res.* **32**, 1–6 (2021). https://doi.org/10.1007/s11676-020-01155-1

(10) Zha, Y., Gao, J. & Ni, S. Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. Int. J. Remote Sens. 24, 583–594 (2003).

(11) Kaimaris, D.; Patias, P. Identification and area measurement of the built-up area with the built-up index (bui). Int. J. Adv. Remote Sens. GIS 2016, 5, 1844–1858.

(12) Xu, H. A new index for delineating built-up land features in satellite imagery. Int. J. Remote Sens. 29, 4269–4276 (2008).