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Urban Change Detection and Growth Analysis (2014–2024): A Remote Sensing Study of Riyadh, London, and Seoul

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ABSTRACT

This study examined urban expansion in Riyadh, London, and Seoul between 2014 and 2024 using Landsat 8 and 9 surface reflectance imagery. Four spectral indices – the normalized difference vegetation index (NDVI), normalized difference built-up index (NDBI), built-up index (BUI), and index-based built-up index (IBI) – were utilized in Google Earth Engine (GEE) to categorize built-up and non-built-up areas. An annual threshold-based classification was conducted, and the resulting maps were visualized through image collages and time-series charts to monitor gains, losses, and overall trends. Riyadh demonstrated rapid horizontal growth, with significant built-up expansion in line with national development plans. Conversely, London experienced minimal urban changes, primarily due to planning policies focusing on densification. Seoul exhibited a dual trend of peripheral expansion and inner-city redevelopment driven by population demand and infrastructure projects. The findings revealed substantial variations in urban growth dynamics among the three cities, highlighting the necessity for context-specific remote sensing thresholds. Despite challenges such as vegetation interference and threshold sensitivity, the multi-index approach offers a robust and replicable method for long-term urban change monitoring. This study provides practical insights for urban planners and policymakers aiming to navigate sustainable development amidst increasing urban pressures.

Keywords: urban expansion, remote sensing, Landsat imagery, built-up classification, Google Earth Engine, sustainable development

1. INTRODUCTION

1.1. Urbanization as a Global Trend. Urbanization represents a prominent global trend in the 21st century. In 1950, only approximately 29% of the global population resided in cities; today, over half of the world's inhabitants live in urban areas. Projections indicate that by 2050, nearly 70% of people will be urban dwellers [1]. This rapid urbanization has led to the emergence of numerous megacities; by 2030, approximately 43 cities are expected to exceed 10 million residents [1]. While growing urban populations drive economic progress and innovation, they also present significant challenges. Unplanned or sprawling urban development strains infrastructure and land resources, resulting in unsustainable growth. Currently, urban areas account for about two-thirds of global energy consumption and more than 70% of greenhouse gas emissions [2]. Given the rapid and extensive urban expansion worldwide – the global urban land area is projected to nearly triple from 2000 to 2030 [3] – it is imperative to monitor urban development patterns to inform sustainable planning and policy decisions.

1.2. Remote Sensing for Monitoring Urban Changes. Remote sensing is essential for observing and quantifying urban changes. Satellite imagery offers consistent spatial data over large areas with high detail and frequent revisits, enabling the creation of continuous time series of land-cover changes [4,5]. This synoptic perspective captures the evolution of urban landscapes and is commonly used to detect built-up land expansion at local, regional, and global scales. Monitoring changes in built-up areas – the land covered by buildings and infrastructure – is crucial because they directly reflect city growth. Tracking the expansion of built-up area is vital for urban planning and governance, as the built environment underpins economic and social activities. Accurate long-term monitoring of urban footprints helps planners assess growth patterns, infrastructure needs, and environmental impacts over time. With the growing availability of open satellite data and advanced analytical methods (e.g. cloud-based platforms and time-series analyses), researchers can regularly measure changes in urban extent and built-up density on an annual basis. Remote sensing-based change detection thus offers an objective basis for comparing urbanization trends across cities and decades.

1.3. Study Focus: Riyadh, London, and Seoul. From a comparative perspective, this study analyzes urban change from 2014 to 2024 in three major metropolitan areas–Riyadh, London, and Seoul–representing diverse geographic and developmental contexts. These cities were chosen for their global importance and differing urbanization patterns.

Table 1. *Urban Demographic and Environmental Characteristics of Riyadh, London, and Seoul*

City	Country	Population	Density	Median Age	Income	PM2.5	Waste	Transport	Governance	Climate Risk	RESI (%)	COMM (%)	Green (%)	Water (%)
London	UK	9000000	5600	40.5	48000	13	Advanced	Excellent	London Auth.	Low	38	35	25	2
Seoul	South Korea	9700000	16400	43.7	42000	23	Advanced	Excellent	Metro	Low	40	35	20	5
Riyadh	Saudi Arabia	7600000	4000	30.8	22000	60	Moderate	Moderate	Governorate	Moderate	45	30	15	10

Note: Population, density, income, pollution, transport, governance, climate risk, and land-use distribution figures are approximate and intended to provide context for each city.

Table 1 summarizes key demographic and environmental characteristics of the three study cities, including population size, urban density, median age, income, $PM_{2.5}$ pollution levels, waste management status, public transport quality, governance structure, climate risk level, and land-use distribution. These city-specific indicators provide crucial context for interpreting land-cover change patterns.

1.4. Objectives . This study examined urban expansion in Riyadh, London, and Seoul from 2014 to 2024 by employing remote sensing indices. The primary objectives are as follows:

- Quantification of built-up changes using NDVI, NDBI, BUI, and IBI.
- Comparison of urban growth trends across the three cities with different development contexts.
- Evaluation of index performance in capturing urbanization under varying environmental and urban conditions.
- Analysis of gain and loss in built-up areas to identify dynamic changes.
- Support for urban planning through visual tools and data that inform sustainable development strategies.

2. DATASET AND TOOLS

2.1. Dataset. This study used yearly Landsat imagery from 2014 to 2024 to examine land-cover transformations in Riyadh, London, and Seoul. The dataset included Landsat 8 and 9 Surface Reflectance images at 30-meter resolution, accessed via GEE using specific path/row identifiers corresponding to each city's location.

Table 2 provides the Landsat 8 and 9 band designations used in this study. Notably, bands 4 (red) and 5 (near-infrared) were used for NDVI calculation, and bands 5 (NIR) and 6 (SWIR1) for NDBI calculation, among others (e.g., a green band and SWIR for the water index component of IBI).

3. METHODOLOGY

This study employed a systematic workflow to monitor and analyze urban growth in the three cities.

3.1. Path/Row Selection and Imagery Access. Using USGS EarthExplorer, the appropriate WRS-2 path and row values were identified for each city's Landsat scenes. Landsat 8 and 9 surface reflectance images were then obtained through GEE. One nearly cloud-free image per year (2014–2024) was selected for each city to represent annual conditions. To reduce seasonal variability, images were chosen from the same month each year (and on similar dates when feasible), ensuring consistency of vegetation status and minimizing seasonal bias in the index values.

Table 2. *Landsat 8 OLI and TIRS Band Designations and Resolutions*

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43 - 0.45	30
Band 2 - Blue	0.45 - 0.51	30
Band 3 - Green	0.53 - 0.59	30
Band 4 - Red	0.64 - 0.67	30
Band 5 - Near Infrared (NIR)	0.85 - 0.88	30
Band 6 - SWIR 1	1.57 - 1.65	30
Band 7 - SWIR 2	2.11 - 2.29	30
Band 8 - Panchromatic	0.50 - 0.68	15
Band 9 - Cirrus	1.36 - 1.38	30
Band 10 (TIRS) 1 - Thermal Infrared	10.60 - 11.19	100
Band 11 (TIRS) 2 - Thermal Infrared	11.50 - 12.51	100

Note: NDVI = (Band 5 – Band 4) / (Band 5 + Band 4); NDBI = (Band 6 – Band 5) / (Band 6 + Band 5); BUI = (NDBI – NDVI) / (NDBI + NDVI); IBI uses a combination of NDBI, NDVI, and a Modified NDWI (which uses Band 3 and Band 6). All indices were calculated on GEE with these band assignments.

Table 3. *Formulas for Spectral Indices Used in Urban Classification*

Index	Equation
NDVI (Normalized Difference Vegetation Index)	(NIR - Red) / (NIR + Red) = (Band 5 - Band 4) / (Band 5 + Band 4)
NDBI (Normalized Difference Built-up Index)	(SWIR - NIR) / (SWIR + NIR) = (Band 6 - Band 5) / (Band 6 + Band 5)
BUI (Built-up Index)	(NDBI - NDVI) / (NDBI + NDVI)
IBI (Index-based Built-up Index)	(NDBI - (NDVI + MNDWI)) / (NDBI + (NDVI + MNDWI)) MNDWI = (Green - SWIR) / (Green + SWIR) = (Band 3 - Band 6) / (Band 3 + Band 6)

3.2. Index Calculation in GEE. Four spectral indices were computed using the selected Landsat bands for each image (Table 3).

Threshold values were applied to each index to classify pixels as built-up or non-built-up. From 2014 to 2024, each city used a fixed threshold per index, determined through visual calibration to minimize misclassification. For example, Seoul's dense vegetation cover required a stricter NDVI threshold to avoid labeling vegetated areas as built-up, whereas Riyadh's arid environment required adjusting NDVI to detect sparse vegetation over bare soil. The thresholds (detailed in Table 3) were maintained at a constant level for all years to ensure temporal consistency and comparability. Table 4 lists the mathematical formulas of these indices as implemented. GEE's expression syntax was used to calculate each index from the Landsat bands, and annual index maps were exported for analysis.

These four indices have well-established uses in urban remote sensing: the NDBI was originally proposed as an automated means to map built-up areas from Landsat TM imagery [10], while the IBI was developed to delineate built-up land features by combining built-up and vegetation indices [11]. In this study, the chosen indices and thresholds were tailored to each city's conditions (e.g., accounting for Riyadh's sparse vegetation and Seoul's abundant greenery) to improve classification accuracy.

3.3. Classification and Area Estimation. Using the binary masks derived from each index (built-up vs. non-built-up), the pixel count of built-up area was calculated and converted to area (square kilometers) for each city and year. This provided annual estimates of built-up and non-built-up land area under each index.

4. RESULTS AND DISCUSSION

This section presents the spatial and quantitative outcomes of the urban change analysis for Riyadh, London, and Seoul from 2014 to 2024. The results derive from the spectral index classification maps (NDVI, NDBI, BUI, IBI), gain/loss spatial comparisons, and time-series graphs. The findings highlight the direction and magnitude of urban transformation in each city, illustrating how built-up and non-built-up areas evolved over the decade. Each city is discussed in turn, through visual interpretation of the classification maps and detailed analysis of the index-based trends, supported by the corresponding figures and graphs.

4.1. Riyadh.

4.1.1. Index-Based Urban Change (2014--2024). RGB and index maps (NDVI, NDBI, BUI, IBI) show Riyadh's steady outward expansion, especially in the north, east, and southeast (Figure 1a). Uniform thresholds ensured that changes reflect real growth. NDVI underestimated built-up land in earlier years due to sparse desert vegetation, while NDBI captured expansion

Table 4. *Threshold Values for Built-up Classification (2014 vs. 2024)*

City	Index	2014 Threshold (y1)	2024 Threshold (y2)
Riyad	NDVI	0.20	0.20
Riyadh	NDBI	0.05	0.05
Riyadh	BUI	-0.22	-0.22
Riyadh	IBI	-0.62	-0.62
London	NDVI	0.15	0.15
London	NDBI	0.04	0.04
London	BUI	-0.22	-0.22
London	IBI	-0.55	-0.55
Seoul	NDVI	0.19	0.19
Seoul	NDBI	0.04	0.04
Seoul	BUI	-0.20	-0.20
Seoul	IBI	-0.55	-0.55

Note: For each city and index, a single fixed threshold is used for all years (2014–2024).

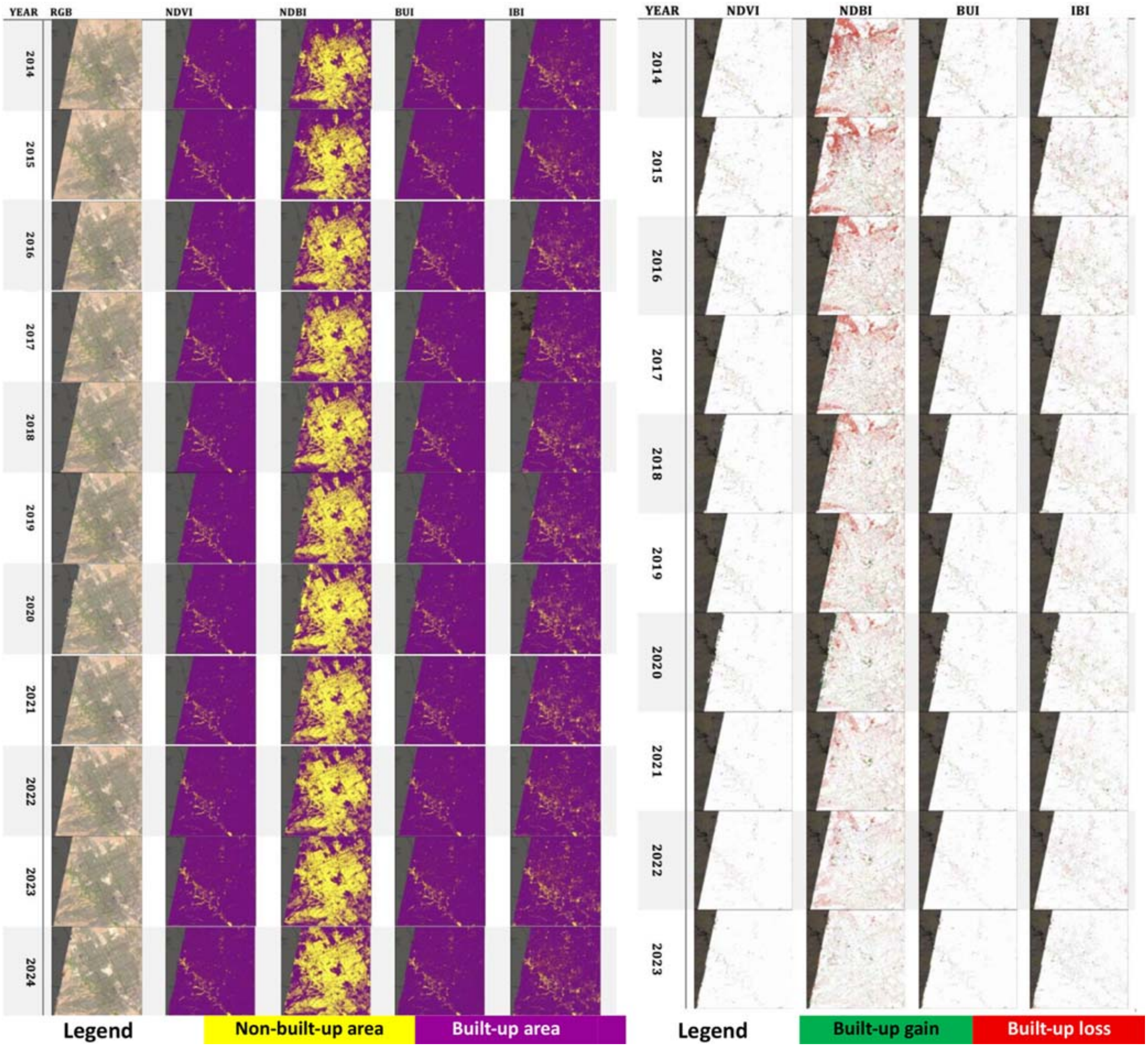

Figure 1. (*a*) Annual built-up vs. non-built-up classification maps and (b) built-up gain/loss maps for Riyadh (2014–2024). In (a), purple areas indicate built-up land and yellow areas indicate non-built-up land for each year. In (b), green areas show new development (gain) and red areas show reclassified loss of built-up land, each year compared to the 2024 baseline.

effectively but showed minor spectral fluctuations. BUI, integrating NDVI and NDBI, clearly outlined urban boundaries and highlighted infill within the core. IBI offered a more conservative but less noisy depiction, emphasizing stable urban centers. Overall, the maps indicate consistent horizontal growth, with new development zones emerging every 1–2 years at the city's fringes.

4.1.2. Gain and Loss Analysis (2014--2024). Figure 1b shows built-up gains (green) concentrated on Riyadh's periphery—north, east, and southeast—linked to suburban growth, ring-road extensions, and industrial projects. Major surges occurred in 2016–2018 and 2021–2023, aligning with Vision 2030 housing and infrastructure initiatives. Losses (red) were minimal, primarily in transitional construction or redevelopment sites that were cleared before rebuilding. The largest net expansion occurred from 2018 to 2020, with further outward growth sustained after 2021. Overall, gains far outweighed losses, confirming a persistent outward expansion with only minor, temporary contractions.

4.1.3. Time-Series Analysis (2014--2024). Figure 2 summarizes Riyadh's temporal dynamics.

- **Built-up area:** NDVI and BUI recorded the largest extents, increasing from ~1,250 km^2 in 2014 to over 1,350 km^2 in 2024, with a sharp peak in 2015, a decline until 2019, and recovery thereafter. IBI followed the same trend at slightly lower values (~1,210 to 1,270 km^2). In contrast, NDBI declined from ~792 to ~702 km^2, underestimating growth due to SWIR sensitivity to bright desert soils.
- **Non-built-up area:** All indices indicated a decline. NDVI/BUI dropped from ~340 to 250 km^2, and NDBI

from ~380 to 320 km^2. IBI reported larger values (~800–890 km^2) but still showed a downward trend, consistent with conservative classification of urban land.

- **Annual gain:** NDBI recorded the highest additions (>60 km^2 in most years, peaking near 90 km^2 in 2020), but much of this reflected temporary spectral changes. IBI and BUI showed steadier gains (10–40 km^2), while NDVI detected <20 km^2 annually, affected by vegetation variability.
- **Annual loss:** NDBI reported unrealistically high losses (60–75 km^2 annually), revealing over-sensitivity. IBI and BUI showed stable values (15–30 km^2), and NDVI only minor, steady losses (~10–20 km^2), likely from seasonal vegetation shifts.

Except for NDBI artifacts, the indices confirm that once land was converted to urban use, it rarely reverted. Riyadh's urban growth during 2014–2024 was effectively irreversible and outward-oriented.

4.2. London.

4.2.1. Index-Based Urban Change (2014--2024).

Figure 3a shows London's stable urban footprint with only localized changes. NDVI underestimated built-up land in earlier years due to the abundance of vegetation (parks, gardens, and tree-lined streets). However, from 2017, small increases appear, linked to redevelopment and brownfield housing projects. NDBI consistently highlighted dense urban cores (Central London, Canary Wharf, Thames corridors) with little outward change. BUI emphasized slight intensification rather than sprawl, reflecting infill within existing boundaries. IBI mapped the broadest extent, occasionally overestimating built-up areas in suburban zones where vegetation and structures intermingle. Overall, London's changes reflect infill, regeneration, and densification, not horizontal expansion.

4.2.2. Gain and Loss Analysis (2014--2024).

Figure 3b shows dispersed but modest gains, mainly in central and inner-city boroughs (e.g., King's Cross, Stratford, Crossrail corridors). Peaks occurred in 2016, 2020, and 2023, aligning with major redevelopment completions. Losses were minimal, often temporary clearances during regeneration or minor classification shifts (e.g., vegetation regrowth). Across all indices, gains outweighed losses. BUI and NDBI captured sharper growth in dense districts, while NDVI and IBI reflected subtle changes in mixed-use or vegetated areas. Together, these results confirm London's incremental, controlled transformation, driven by redevelopment and density increases rather than sprawl.

4.2.3. Time-Series Analysis (2014--2024).

- **Built-up area trends:** Figure 4 (top-left) shows London's built-up area remained stable, with only minor fluctuations. IBI reported the largest extents (220–330 km^2), peaking in 2019 during redevelopment surges, then stabilizing near 225 km^2 by 2024. BUI averaged 130–180 km^2, dipping slightly in 2016–2018 before recovering. NDBI, the lowest (50–140 km^2), declined to 2018 then rose to its maximum in 2024. NDVI ranged from 60–150 km^2, peaking in 2024, reflecting improved classification of redeveloped zones. Collectively, these patterns confirm limited net growth, driven by infill and regeneration rather than sprawl.

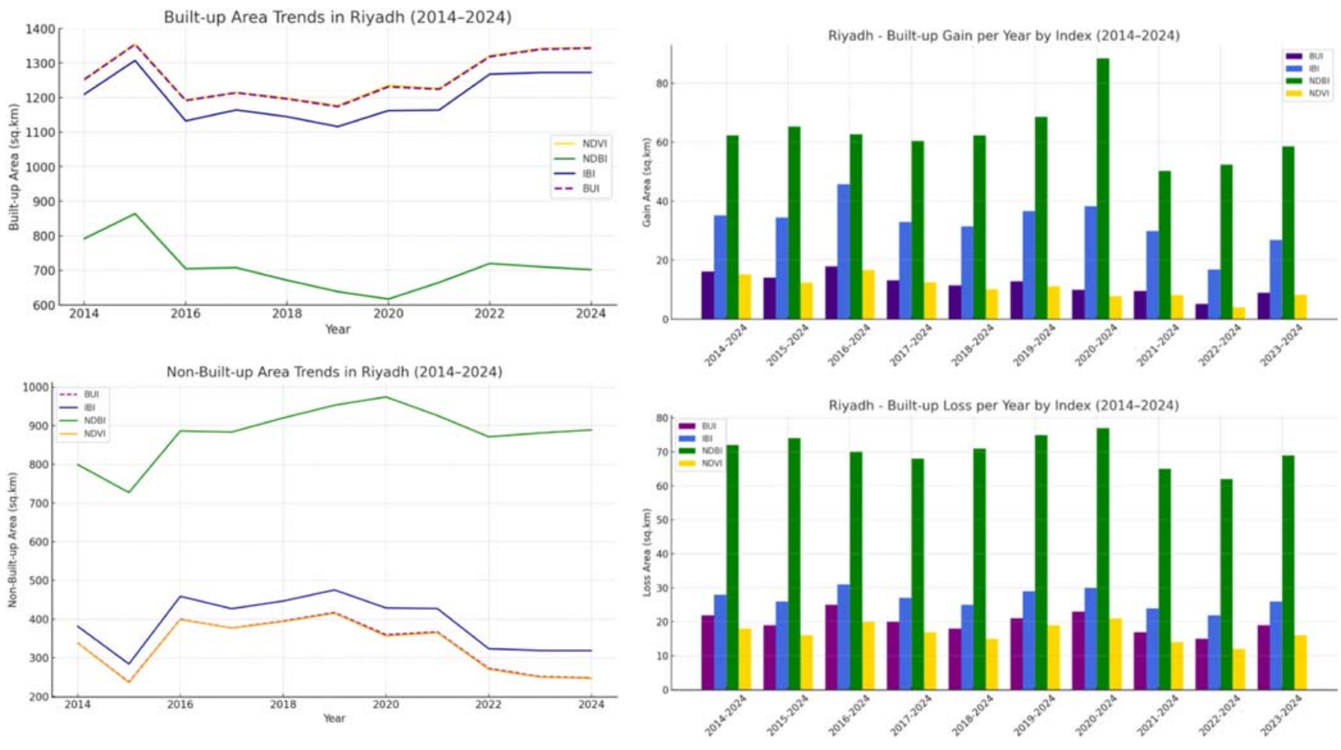

Figure 2. Time-series plots of Riyadh's built-up dynamics (2014–2024): (top-left) Total built-up area; (bottom-left) total non-built-up area; (top-right) annual built-up area gain; (bottom-right) annual built-up area loss. These plots compare results from four indices (NDVI, NDBI, BUI, IBI), highlighting overall growth in built-up extent, the corresponding loss of open land, and the magnitude of yearly changes. (Note: NDBI's higher gain/loss fluctuations reflect its index sensitivity in arid conditions.)

- **Non-built-up area trends:** Figure 4 (bottom-left) indicates little overall change. NDVI and NDBI consistently showed ~1,490–1,540 km^2, reflecting London's preserved parks and green belt. IBI dropped from ~1,380 to 1,300 km^2 during densification (2014–2018), then recovered slightly. BUI remained 1,400–1,470 km^2, with a gentle decline after 2017 linked to incremental housing infill. In summary, vegetation-sensitive indices highlight stable green cover, while built-up–focused indices captured subtle infill-driven reductions.
- **Annual built-up gain:** Figure 4 (top-right) shows modest yearly gains across all indices, consistent with London's slow growth. IBI and NDVI registered 75–90 km^2 per year, BUI ~55–70 km^2, and NDBI <90 km^2. The absence of sharp peaks reflects incremental redevelopment projects (e.g., brownfield conversions, small housing estates).
- **Annual built-up loss:** Figure 4 (bottom-right) shows consistently low losses. IBI reported the largest area (~80–100 km^2 mid-decade, declining to ~70 km^2 by 2024), which was mostly attributed to temporary demolition before redevelopment. BUI losses averaged 30–40 km^2, with a small rise in 2017–2018. NDBI losses stayed under 40 km^2, with slight late increases linked to vegetation initiatives or temporary clearances. NDVI showed the smallest (10–25 km^2), reflecting transient vegetation regrowth. Overall, losses were temporary and offset quickly by redevelopment, with no lasting contraction of the urban footprint.

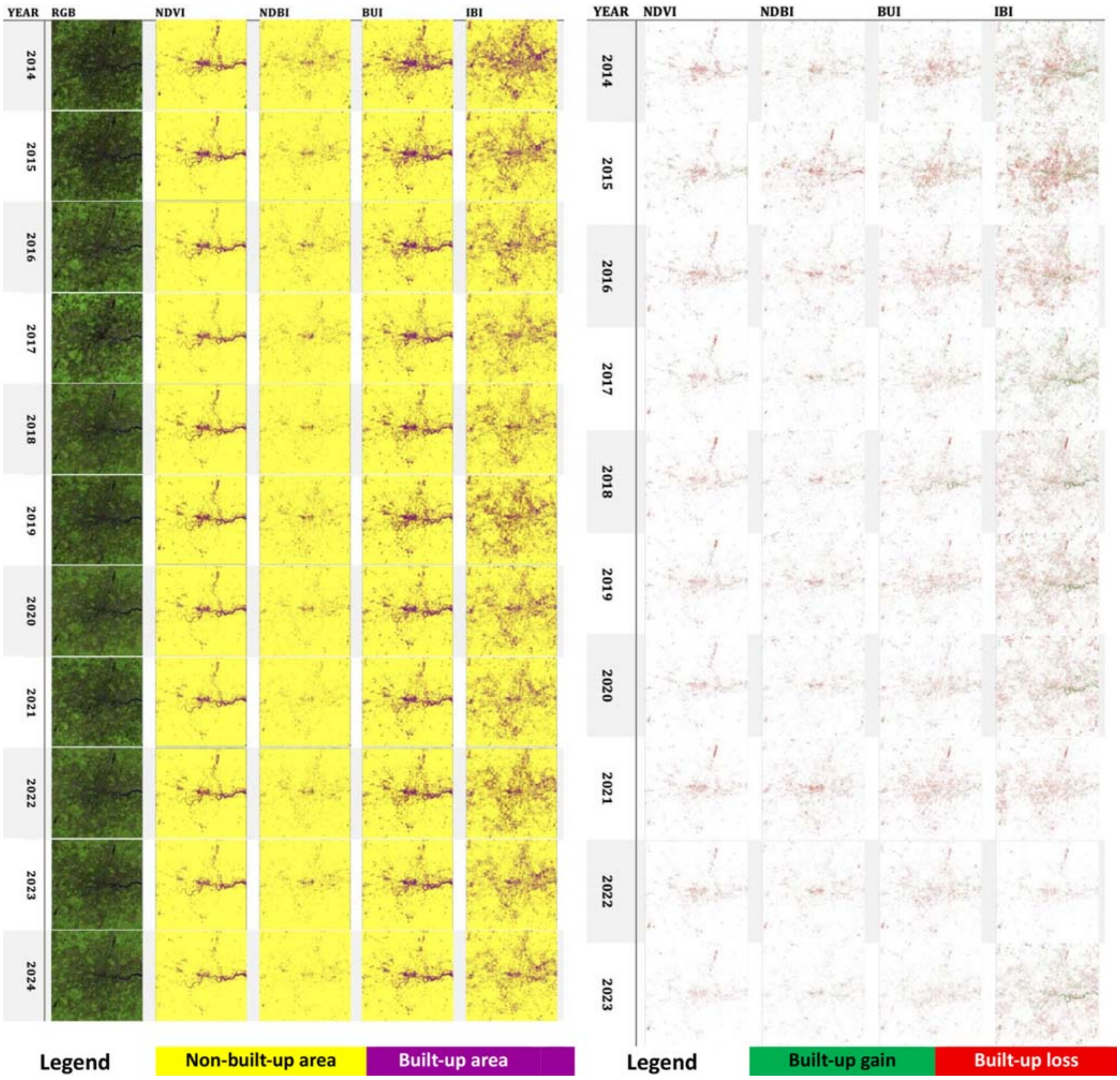

Figure 3. (a) Annual built-up vs. non-built-up classification maps and (b) built-up gain/loss maps for London (2014–2024). In (a), built-up areas are shown in purple and non-built areas in yellow. In (b), green areas denote where new development occurred (gains) and red areas denote where previously built-up areas were reclassified as non-built (losses), relative to 2024.

London's time series confirms a mature, stable urban system, characterized by incremental redevelopment, strong green space preservation, and negligible permanent losses. Growth occurred primarily through densification and regeneration, reinforcing the city's controlled planning framework.

4.3. Seoul.

4.3.1. Index-Based Urban Change (2014--2024). Figure 5a shows Seoul's dynamic transformation, with shifts in both central districts and expanding peripheries. NDVI initially underestimated built-up land due to the city's extensive vegetation and green infrastructure, but after 2017 it captured clearer urban delineation as pressure on fringe green areas intensified. NDBI consistently highlighted dense cores (e.g., Gangnam, Yeouido, downtown) and later detected suburban expansion into Goyang and Hanam after 2018. BUI outlined the built environment well, revealing stable cores and outward suburban growth post-2018. IBI showed sharp expansion from 2014–2017, then a decline during 2017–2019 linked to demolition and redevelopment cycles, before stabilizing after 2020. Together, the indices illustrate Seoul's dual trajectory: outward suburban expansion coupled with vertical redevelopment and densification of central districts, reflecting national housing strategies, new town projects, and transport-led growth.

4.3.2. Gain and Loss Analysis (2014--2024). As shown in Figure 5b, gains (green) were concentrated in outer districts and satellite cities—especially Songpa, Gangdong, and Gyeonggi Province—peaking in 2016–2017 and again in 2023, coinciding with housing drives and delayed infrastructure projects. Losses (red) were more pronounced than in Riyadh or London, largely between 2016–2019 in central areas under redevelopment. IBI registered the greatest losses, often exaggerating demolition phases by classifying cleared or debris-covered land as non-built. By 2020 and especially 2023, strong net gains reappeared, led by BUI and NDBI, as suburban projects were completed and redevelopment areas reoccupied. Overall, Seoul's gain–loss dynamics reflect its two-pronged **strategy**: continuous inner-city redevelopment, producing cycles of temporary decline, combined with sustained suburban expansion. IBI captured the disruption of redevelopment, while BUI and NDBI provided clearer evidence of long-term growth. These patterns underscore Seoul's compact, high-density planning in the core, balanced with outward expansion into planned satellite cities.

4.3.3. Time-Series Analysis (2014--2024).

- **Built-up area trends:** Figure 6 (top-left) shows Seoul's built-up area peaking around 2017, then declining before stabilizing by 2024. IBI recorded the highest extent (~775 km^2 in 2017), which dropped to approximately 369 km^2 as redevelopment cycles cleared central districts. BUI peaked at ~509 km^2 in 2017, declining steadily to ~279 km^2. NDVI spiked to ~392 km^2 in 2017 (construction-driven vegetation loss) before falling to ~227 km^2 by 2024. NDBI peaked near ~366 km^2 in 2017, then declined to ~150 km^2 by 2024. The patterns reflect rapid mid-decade expansion followed by demolition and rebuilding, with stabilization by the early 2020s.
- **Non-built-up area trends:** Figure 6 (bottom-left) shows the inverse. IBI dropped sharply to ~816 km^2 in 2017, then rebounded to ~1,222 km^2 by 2024 as cleared sites were reclassified as non-built. NDBI showed the largest non-built extents (~1,225–1,448 km^2), indicating underestimation of built-up areas in some contexts. BUI remained relatively stable (~1,083–1,312 km^2), while NDVI fluctuated between ~1,199

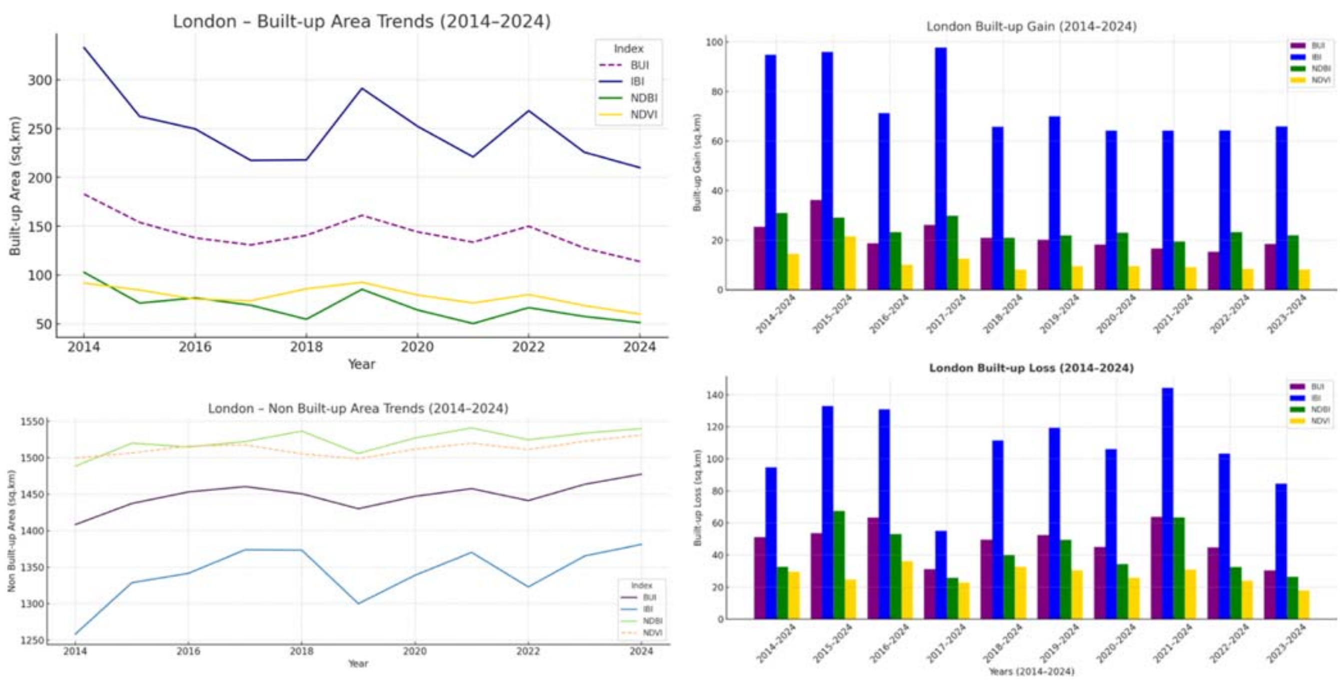

Figure 4. Time-series plots of London's urban land dynamics (2014–2024): (a) Built-up area; (b) non-built-up area; (c) annual built-up gain; (d) annual built-up loss. Results are shown according to four indices (NDVI, NDBI, BUI, IBI). London's curves demonstrate minimal net change in total built-up or open areas, with slow gains and very small losses reflecting a stable, mature city with growth occurring through gradual redevelopment rather than expansion.

and ~1,364 km^2, reflecting Seoul's resilient green cover. Overall, non-built-up land recovered after 2018, underscoring the city's integration of vegetation into its redevelopment efforts.

- **Annual built-up gain:** Figure 6 (top-right) shows IBI capturing the largest gains, peaking at ~165 km^2 in 2014–2015 and rising again to ~125 km^2 in 2023–2024. BUI showed moderate but steady gains (30–70 km^2), with peaks in 2016 and 2023. NDBI gains rose gradually to ~55 km^2 by 2024, reflecting fringe expansion. NDVI was more variable (25–70 km^2), with early spikes tied to rapid vegetation loss. The trends highlight two growth phases—early (2014–2016) and late (2023–2024)—separated by a redevelopment lull.
- **Annual built-up loss:** Figure 6 (bottom-right) reveals the disruptive impact of redevelopment. IBI showed extreme losses (~200–500 km^2) between 2017 and 2020, declining to ~150 km^2 by 2024. BUI losses peaked at ~260 km^2 in 2017–2018 before stabilizing below 100 km^2. NDBI registered mid-decade losses (~130–250 km^2), which decreased to approximately 50 km^2 by 2024. NDVI losses (100–200 km^2) peaked in 2017–2018 as cleared land temporarily re-vegetated. Overall, losses were temporary and redevelopment-driven, with balance restored by the early 2020s.

Seoul's time series highlights a cyclical pattern: rapid expansion through 2017, followed by heavy demolition and redevelopment through 2020, and then stabilization with renewed suburban growth by 2023–2024. Unlike Riyadh's steady outward growth or London's incremental densification, Seoul's urban change was

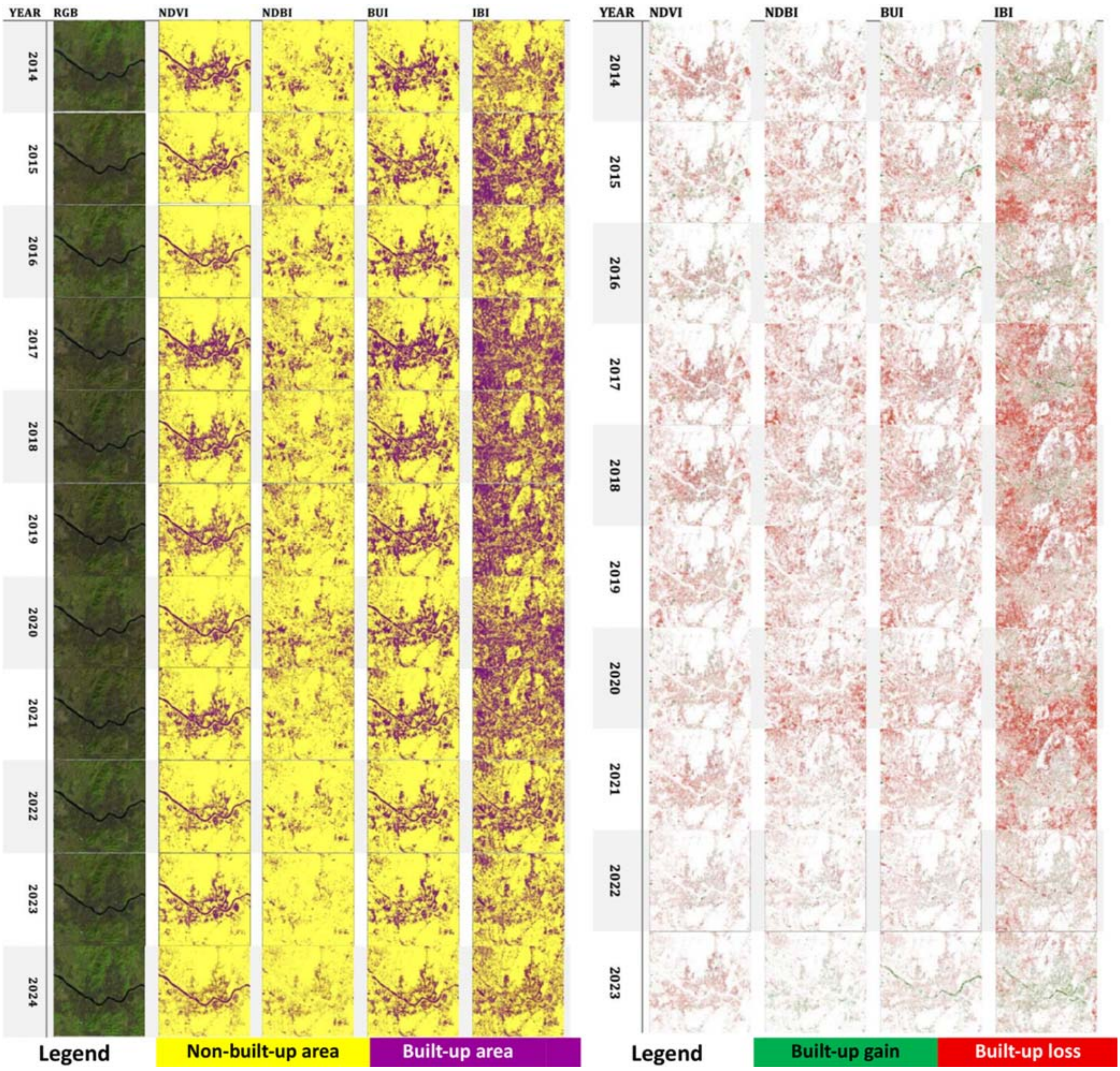

Figure 5. (a) Annual built-up vs. non-built-up classification maps and (b) built-up gain/loss maps for Seoul (2014–2024). In (a), purple indicates built-up and yellow indicates non-built-up areas for each year. In (b), green highlights areas of new urban development (gain) and red highlights areas of built-up land loss or demolition, compared to 2024.

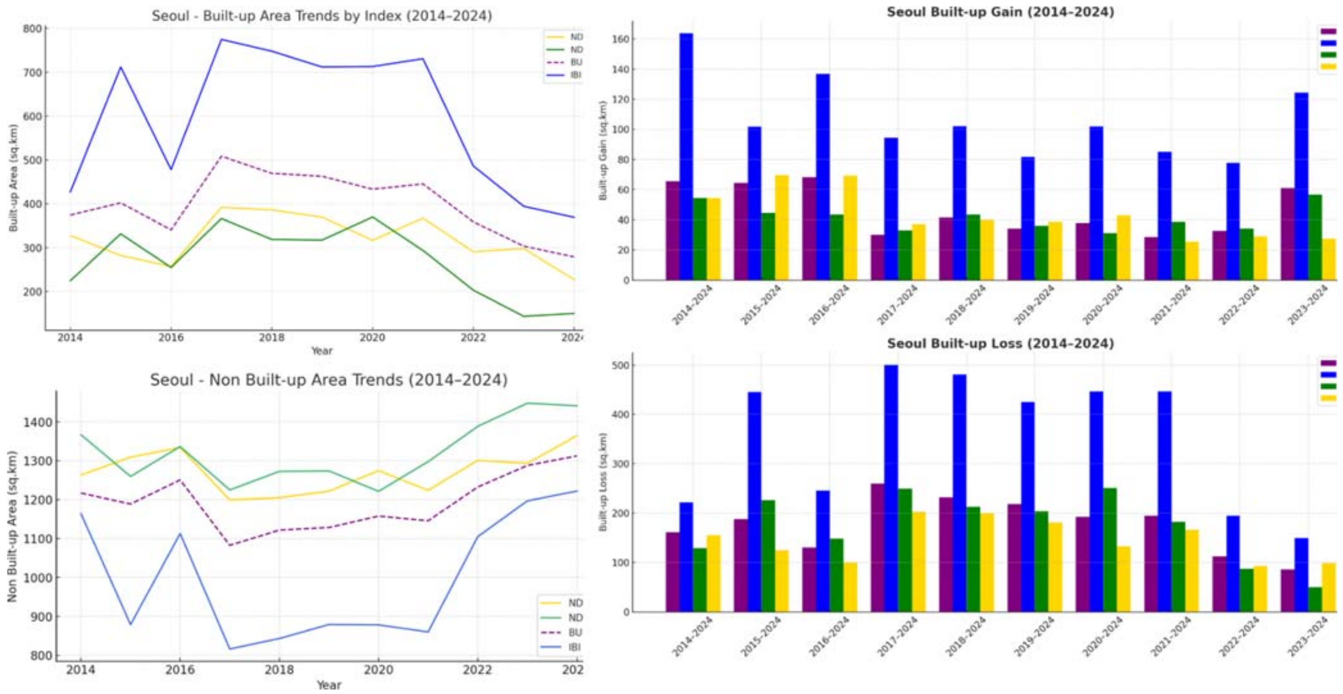

Figure 6. Time-series plots of Seoul's urban land dynamics (2014–2024): (a) Built-up area; (b) non-built-up area; (c) annual built-up gains; (d) annual built-up losses. Each panel shows results from NDVI, NDBI, BUI, and IBI. Seoul's trends are characterized by a mid-period peak in built-up area followed by stabilization, reflecting its redevelopment cycle. The substantial spikes in annual gains and losses captured by IBI highlight periods of rapid construction and demolition, respectively, whereas the other indices indicate more moderate, continuous change and recovery of open spaces following redevelopment.

highly dynamic, reflecting its dual strategy of core redevelopment and suburban expansion.

5. CONCLUSIONS

This study analyzed urban changes in Riyadh, London, and Seoul from 2014 to 2024 using multi-index remote sensing techniques in Google Earth Engine. By employing four spectral indices (NDVI, NDBI, BUI, and IBI) and a consistent threshold-based classification, the analysis captured diverse patterns of urban expansion: Riyadh demonstrated rapid outward growth of its built-up area, London exhibited minimal change constrained by stringent planning regulations, and Seoul showcased a combination of peripheral expansion and significant central redevelopment.

Several limitations were noted in the methodology, including classification errors due to index sensitivity and the challenge of vegetation masking built-up surfaces (especially in green cities like London and Seoul). In some cases, observed trends in the indices were influenced by how each index responds to mixed land cover (for example, the oversensitivity of IBI in redevelopment zones), rather than purely physical land-use change. These considerations underscore the importance of methodological transparency and selecting the optimal combination of indices for urban change detection.

Overall, the multi-index remote sensing approach proved to be a valuable tool for long-term urban monitoring. When applied with clear methodological considerations and calibrated to local conditions, it can provide city officials and planners with regular, objective insights into development patterns. For Riyadh, the findings underscore the pace of sprawl and the need for sustainable growth management; for London, they highlight the success of containment policies and the focus on regeneration; for Seoul, they reveal the intensity of redevelopment and the importance of balancing growth with green space preservation.

Moving forward, enhancements such as incorporating machine learning classification (to learn optimal thresholds or classifications automatically), using time-series analysis for continuous monitoring, and integrating socio-economic datasets (population, infrastructure, policy changes) could provide an even more comprehensive understanding of urban dynamics. Despite its challenges, remote sensing – especially with freely available satellite data and powerful cloud platforms – offers a replicable and scalable method for cities worldwide to monitor development, evaluate land-use changes, and inform more sustainable urban planning decisions.

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REFERENCES

(1) United Nations. *World Urbanization Prospects: The 2018 Revision*. Department of Economic and Social Affairs, Population Division (2018).

(2) UN-Habitat. *World Cities Report 2020: The Value of Sustainable Urbanization*. United Nations Human Settlements Programme (2020).

(3) Seto, K. C., Güneralp, B. and Hutyra, L. R. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. U.S.A.* **109**, 16083–16088 (2014).

(4) Zhou, Y., Smith, S. J., Zhao, K. and Imhoff, M. A cluster-based method to map urban area from MODIS land surface temperature and NDVI. *Remote Sens. Environ.* **152**, 1–14 (2014).

(5) Weng, Q. Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. *Remote Sens. Environ.* **117**, 34–49 (2012).

(6) Zha, Y., Gao, J. and 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).

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

(8) Alghamdi, A., Aldomae, M. and Mubarak, F. Monitoring and modeling of urban expansion using GIS and remote sensing techniques in Riyadh, Saudi Arabia. *Egypt. J. Remote Sens. Space Sci.* **20**, 211–217 (2017).

(9) Office for National Statistics (ONS). Population estimates for the UK, England and Wales, Scotland and Northern Ireland: mid-2022. https://www.ons.gov.uk/ (2023).

(10) Gallent, N., Andersson, J. and Bianconi, M. *Planning on the Edge: The Context for Planning at the Rural-Urban Fringe*. Routledge (2006).

(11) Korea Statistical Information Service (KOSIS). https://kosis.kr (2024).