

Urban Expansion and the Loss of Ecological Infrastructure

Mapping the Sustainability Costs of Metropolitan Growth

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Abstract

Rapid metropolitan growth converts ecologically functional land into built surfaces, yet the sustainability costs of this process are fragmented across land-change, habitat, ecosystem-service, and urban-climate research. This systematic review synthesised the evidence on the effects of urban expansion on ecological infrastructure and converted the evidence into similar sustainability-cost spaces. Scopus, Web of Science Core Collection, and Green File were searched between 2016 and 2026, and 926 records were found. After eliminating 126 duplicates, 800 records were filtered, 140 full texts were evaluated, and 25 open-access primary studies were eligible. Structured evidence mapping, comparative thematic analysis, and methodological quality appraisal were used to synthesise evidence. It was geographically concentrated in Asia, with lesser contributions from Africa and Europe, and dominated by remote-sensing, GIS, ecosystem-service valuation, InVEST, landscape-metric, and scenario-modelling methods. In all environments, outward and edge expansion continuously transformed forests, wetlands, agricultural land, green space, and other ecological land, and augmented fragmentation and impervious cover. Among the consequences were decreased habitat quality, reduced ecological-service value, decreased carbon and water-regulation capabilities, increased thermal exposure, and loss of localised provisioning. Cities partially greened recovered their services, or realised increased provisioning functions, suggesting that ecological performances are reliant on expansion form, policy, and regional setting. The review illustrates that cumulative sustainability costs are created by metropolitan growth in cases where ecological infrastructure is perceived as fringe land instead of operational city infrastructure. Growth management should be linked to ecological-network protection, ecosystem-service accounting, restoration and spatially explicit monitoring through the planning systems.

Keywords: urban expansion; metropolitan growth; ecological infrastructure; ecosystem services; urban sprawl; habitat quality; green infrastructure; sustainability.

1. Introduction

Metropolitan growth increasingly reorganises land at scales that exceed municipal boundaries, replacing permeable and biologically productive surfaces with built infrastructure. Land-use change reviews indicate that urban conversion results in the loss of ecosystem-related services as it changes the composition, configuration, and functionality of soil systems (Gomes et al., 2021). The recent synthesis of the world also indicates that the studies on land-use change are highly focused in Asia, particularly in China, although the methodological capacity is growing in other regions (Epie et al., 2026). Urban sprawl may

also cause local losses and redistribute a portion of the ecosystem-service impacts to adjacent jurisdictions, making it more difficult to govern metropolitan areas (Yi et al., 2023). Mapping studies, in turn, highlight the necessity to study urban and peri-urban systems at different spatial scales instead of focusing on administrative delimiting factors (Pereira et al., 2024). These trends define metropolitan growth as a land-development process and a cumulative ecological change that needs to be integrated into sustainability evaluation.

An ecological infrastructure offers a good model that links land-cover change to the urban functions that are reliant on nature. Urban green and blue infrastructure reviews demonstrate that urban vegetation, water bodies, wetlands, parks, and ecological networks promote various services (Veerkamp et al., 2021). There is also systematic evidence that green infrastructure and urban agriculture can collaboratively sustain the provisioning, regulating, cultural, and supporting services in various urban environments (Evans et al., 2022). Research on green infrastructure is now considering such assets as multifunctional networks but not as isolated locations due to the impacts of spatial distribution and connectivity on service delivery (Korkou et al., 2023). Informal green areas can also be used to supplement formal networks where planned ecological delivery is limited by high competition in land use (Luo & Patuano, 2023). Ecological infrastructure thus refers to operational green and blue, habitat, and productive land structures whose deterioration can diminish metropolitan resilience.

The sustainability costs of the loss of ecological infrastructure are not limited to the decrease in green area since the urban conversion alters ecological processes. Literature on densely populated areas demonstrates that urban expansion has the potential to reduce the quality of the habitat by moving high-quality habitat to more disturbing conditions (Tang et al., 2023). The imbalances between the supply of ecosystem-related services and the increasing metropolitan demand on water, carbon storage, soil conservation, and food production can also be increased in urban agglomerations as a result of sprawl (Wang and Sun, 2024). The green-infrastructure trade-off reviews demonstrate that benefits in one service can be accompanied by losses or disservices in other services, which cannot be adequately evaluated by areas alone (Zhang and MacKenzie, 2024). Recent synthesis reveals urban green infrastructure has an impact on climate, air quality, and runoff management, but the impact differs depending on the type and size of the infrastructure (Yao et al., 2025). Sustainability assessment should be able to trace explicitly the loss of ecology and the functional cost resulting from the transformation of metropolitan land.

Synthesis has already shed light on key aspects of this relationship, but there still is methodological and geographic imbalance in the literature on urban regions. An analysis of 862 quantitative urban ecosystem-service papers found a wide range of differences in equations, parameters, and transparency of reporting, which limits cross-study comparability (Ma & Yang, 2025). Evidence on South America is still confined to a few countries, even though the area is highly urbanised and important to biodiversity (Muñoz-Pacheco & Villaseñor, 2022). The Russian urban ecosystem-service studies also indicate the lack of spatial coverage, validation, and integration with planning mechanisms (Dushkova et al., 2025). The advantages and multifunctional characteristics of green infrastructure have been more frequently highlighted in green-infrastructure reviews compared with the losses that urban land conversion causes (Jato-Espino et al., 2023). These restrictions suggest that a synthesis based on the analytical process of metropolitan expansion to ecological degradation can make a specific analytical contribution.

Green infrastructure or ecosystem services are commonly a starting point of sustainability reviews, and not metropolitan growth as the cause of change. Literature has bridged ecosystem services, green infrastructure, and solutions based on nature, yet it studies conceptual integration and sustainability advantages (Fang et al., 2023). Evidence on the benefits of green infrastructure reviews organises evidence based on the services that nature provides to cities, such as climate adaptation and health co-benefits (Herath and

Bai, 2024). Systematic evaluations of service mapping focus on approaches, measures, and confirmation, and less on how particular expansion types generate different packages of losses (Pereira et al., 2024). Such a review thus moves the analytic point of departure away from ecological resources to growth pressure and tracks the resultant land, habitat, service, thermal, and hydrological costs. The innovation is the incorporation of these fragmented results into one chain of evidence, which directs the decisions of metropolitan sustainability planning.

In this regard, this review explored the effects of metropolitan expansion on ecological infrastructures and the sustainability costs that arise as a result of the developments. The synthesis was done using four objectives that determined expansion forms, sensitive ecological assets, the sustainability costs, and variability in the spatial contexts and growth patterns. RQ1 examined recurrent patterns of urban and metropolitan expansion, while RQ2 identified ecological infrastructure most consistently lost, degraded, or fragmented. RQ3 addressed environmental and socioeconomic sustainability costs, whereas RQ4 assessed variation across regions, expansion forms, and analytical approaches. This sequence distinguished the spatial process of metropolitan growth from the ecological and socioeconomic consequences that emerge from land transformation. By linking these questions sequentially, the review provides an evidence-based framework for interpreting metropolitan growth as a measurable transformation of ecological capacity.

2. Materials and Methods

2.1 Review Design and Reporting Framework

The literature review was systematic, with evidence mapping and thematic synthesis to combine spatially and methodologically heterogeneous primary research. A systematic review was suitable since the research question involved repetitive associations between metropolitan expansion, ecological-infrastructure change, and sustainability outcomes in a variety of geographic contexts. Identification, screening, eligibility, and inclusion decisions were made transparent and reproducible by reporting according to PRISMA 2020 (Page et al., 2021). The search-reporting components were also formatted with PRISMA-S principles, specifically database names, field restrictions, search expressions, dates, and limits (Rethlefsen et al., 2021). No prospective protocol was registered to review. No statistical meta-analysis was conducted due to the fact that the studies included could not utilise equivalent outcome measures, spatial units, time periods, valuation coefficients, habitat models, and thermal indicators. The review thus considered direction of effects, magnitude of effect, mechanism of effect, and context evidence as complementary evidence and did not impose an incompatible result in an estimate pool.

The analysis model had a pressure-change-cost sequence. The pressure was considered to be urban or metropolitan expansion, the affected spatial system to be ecological infrastructure, and the sustainability costs as the ecological condition or service delivery changes that could be measured. This framework aligned with recent ecology-service mapping reviews which decouple land-change drivers, ecological indicators, and mapped results in urban and peri-urban environments (Pereira et al., 2024). It also addressed methodological issues where urban ecosystem-service assessments often adopt a wide range of indicators whose comparability or validation is often lacking (Ma & Yang, 2025). Evidence was subsequently codified into expansion form, land conversion, fragmentation, habitat quality, ecosystem-service value, regulating functions, provisioning functions, thermal effects, hydrological effects, and planning responses. This framework made it possible to compare without the assumption that the monetary valuation, habitat modelling, land-cover measures, and temperature analysis are measuring the same construct.

2.2. Eligibility Criteria

To include full-text synthesis, eligibility criteria were specified in advance and are outlined in Table 1. The inclusion criteria were that the studies had to be peer-reviewed journal articles, published between 2016 and 2026, and be based on primary empirical, geospatial, or modelling analysis and written in English. The studies were required to consider an urban, metropolitan, peri-urban, or urban-agglomeration context and to measure urban expansion, urban sprawl, built-up growth, or a directly related land-use transition. Eligible consequences were a loss, degradation, fragmentation, or functional change of green infrastructure, wetlands, forests, ecological land, habitat, vegetation, water bodies, ecosystem services, or similar ecological assets. Emphasis on quantifiable environmental change was indicative of the requirement for clear connections between land transformation and ecosystem-service evaluation recognised in the current review of methods (Gomes et al., 2021). The final included corpus had to be available as open access in order to allow full verification of methods and findings.

Articles that were reviews, editorials, conference papers, books, book chapters, or non-peer-reviewed content were excluded; those that were not published within the 2016-2026 timeframe were excluded; and articles without an English translation were excluded. Articles that reported on urban sustainability without quantifying expansion or land transformation were filtered out, as well as articles that quantified urban growth without a measure of an ecological-infrastructure or ecosystem-service outcome. There was also exclusion of pure rural land-change studies and studies that lacked pertinent analysis in terms of spatial, land-use, ecological, and sustainability analysis. These limitations were meant to prevent conceptual overbreadth in the literature on urban ecosystem services, where the language and measurement units are significantly different across studies (Veerkamp et al., 2021). They also made sure that the synthesis did not respond to the title on the generality of the ecological cost of urban settings but the relationship between metropolitan growth and ecological cost.

Table 1
Eligibility criteria for study selection

Criterion	Inclusion criteria	Exclusion criteria
Publication period	Journal articles published from 2016 to 2026	Published before 2016
Publication type	Peer-reviewed primary research article	Review, editorial, conference paper, book/chapter, commentary, non-peer-reviewed item
Language	English	Non-English full text
Access	Legally accessible open full text for the final included corpus	Full text unavailable or access status could not be verified
Setting	Urban, metropolitan, peri-urban, or urban-agglomeration context	Purely rural or non-urban setting without metropolitan linkage
Exposure	Measured urban expansion, sprawl, built-up growth, or related land-use conversion	Urban sustainability discussed without a measurable expansion/land-change component.

Criterion	Inclusion criteria	Exclusion criteria
Outcome	Measured ecological-infrastructure, ecosystem-service, habitat, vegetation, wetland, forest, water, thermal, or comparable sustainability outcome	No ecological-infrastructure, ecosystem-service, land-use, spatial, or sustainability outcome
Evidence	Primary empirical, geospatial, statistical, valuation, or scenario-modelling analysis	Insufficient primary evidence for extraction

Note. Open access was required for the final included corpus; database-level open-access filtering differed by platform. Source. Author's review protocol and eligibility framework.

2.3. Information Sources and Search Strategy

Peer-reviewed literature published between 2016 and 2026 was searched in Scopus, Web of Science Core Collection, and GreenFILE. The broad multidisciplinary coverage of geography, environmental science, ecology, planning, and urban studies was available in Scopus and Web of Science, but the specialised environmental literature was offered via the EBSCOhost platform by GreenFILE. Complementary databases also minimised the reliance on a single indexation system and provided transparent database reporting as advocated by PRISMA-S (Rethlefsen et al., 2021). The peer-reviewed journal articles and English-language records were limited to searches. Open-access filters were directly applied where supported; in the case of GreenFILE, open-access eligibility was checked during full-text evaluation since a similar open-access limiter could not be used in the interface.

Search notions synthesised four phrases of metropolitan growth with ecological-infrastructure phrases and signs of loss or deterioration. Scopus had TITLE-ABS-KEY as the urban-growth block and an abstract-level W/4 proximity condition between ecological terms and loss, degradation, fragmentation, decline, or conversion. Web of Science used Topics as the growth block and Abstract with NEAR/4 as the ecological-loss relationship. In GreenFILE, three Title or Abstract (XB) rows were used that were linked with AND since the interface did not offer separate title and abstract fields. Table 2 replicates the expressions and filters as they are written in the database. This field-sensitive methodology balanced recall and relevance, which is in line with search-design advice that suggests describing database syntax instead of showing a single generic text as being universally applicable (Rethlefsen et al., 2021).

Table 2
Database-specific search strategy and records retrieved

Database	Search implementation	Records
Scopus	TITLE-ABS-KEY("urban expansion" OR "urban sprawl" OR "metropolitan growth" OR "built-up expansion") AND ABS(("ecosystem service*" OR "green infrastructure" OR "urban green space*" OR "habitat quality" OR "ecological land" OR wetland* OR forest*) W/4 (loss* OR degrad* OR fragment* OR decline* OR conversion)) AND SUBJAREA(ENVI OR EART OR SOCI) AND PUBYEAR > 2015 AND PUBYEAR < 2027 AND DOCTYPE(ar) AND SRCTYPE(j) AND LANGUAGE(english) AND OA(ALL)	324
Web of Science Core Collection	Topic: ("urban expansion" OR "urban sprawl" OR "metropolitan growth" OR "built-up expansion") AND Abstract: (("ecosystem service*" OR "green infrastructure" OR "urban green space*" OR "habitat quality" OR "ecological land" OR wetland* OR forest*) NEAR/4 (loss* OR degrad* OR fragment* OR decline* OR conversion)); filters: 2016-2026, Article, All Open Access, English.	392

Database	Search implementation	Records
GreenFILE (EBSCOhost)	XB ("urban expansion" OR "urban sprawl" OR "metropolitan growth" OR "built-up expansion") AND XB ("ecosystem service*" OR "green infrastructure" OR "urban green space*" OR "habitat quality" OR "ecological land" OR wetland* OR forest*) AND XB (loss* OR degrad* OR fragment* OR decline* OR conversion); filters: 2016-2026, Peer Reviewed, Academic Journals, English.	210
Total	Records identified before duplicate removal	926

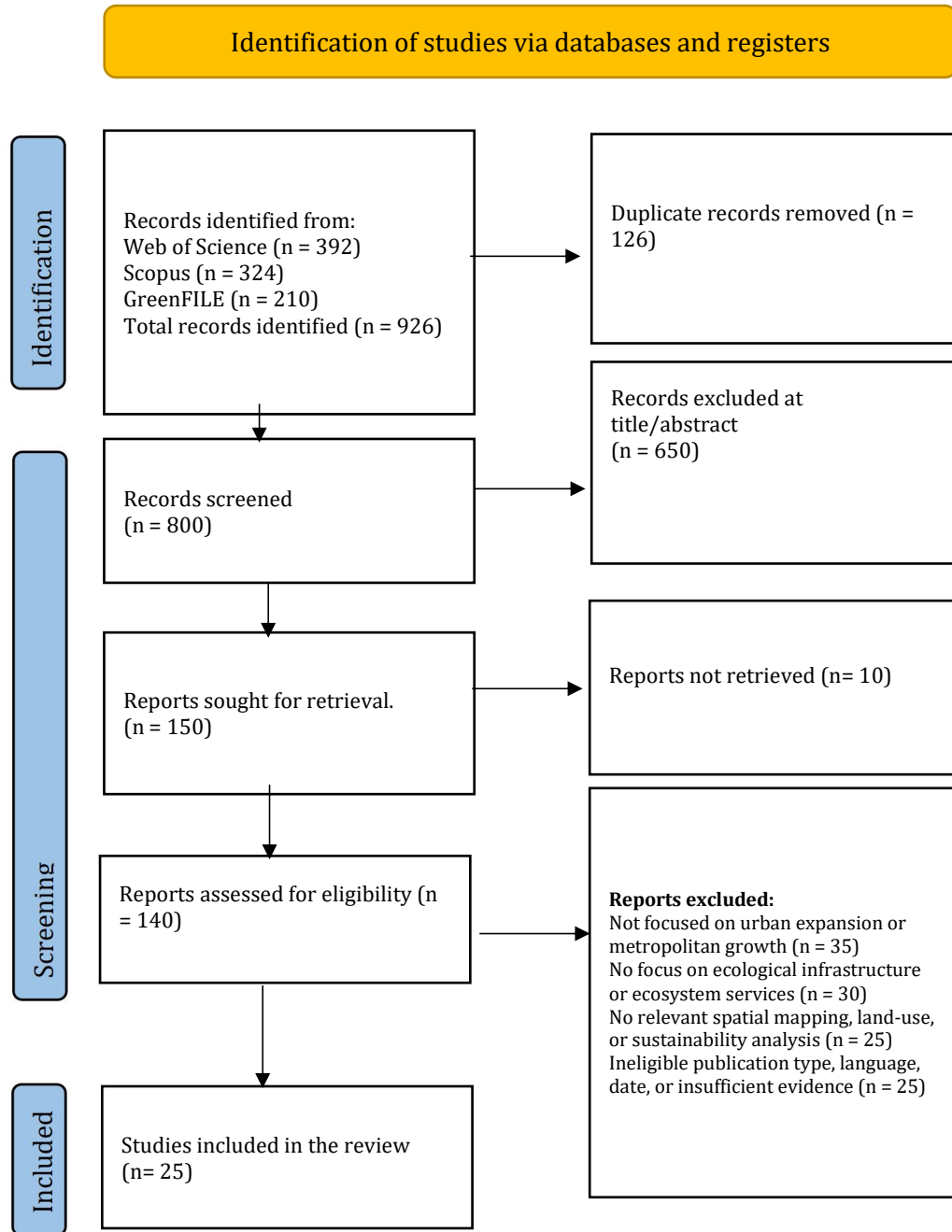
Note. Searches covered publications from 2016 to 2026. Database-specific syntax was retained to preserve reproducibility. Source. Author's database searches.

2.4. Screening and Study Selection

The searches found 926 records: 324 in Scopus, 392 in the Web of Science Core Collection, and 210 in the GreenFILE. The records were exported to Microsoft Excel, where duplicate records were manually identified by comparing DOI, title, first author, and publication year, and similar titles were verified by checking for near-identical titles before deletion. The number of unique records in title-and-abstract screening decreased to 800 after 126 duplicates had been eliminated. Titles and abstracts were independently screened by two reviewers against the eligibility criteria, with any disagreement resolved by discussion and consensus. At this point, 650 records were eliminated. The remaining 150 reports were requested to be retrieved, and 10 were not retrievable, so 140 full-text reports were eligible for assessment. The full texts were evaluated by both reviewers separately and by consensus in case of discrepancy. The entire PRISMA 2020 selection pathway is shown in Figure 1 (Page et al., 2021).

Full-text evaluation eliminated 115 reports. Thirty-five were not about urban expansion or metropolitan growth, 30 were not about an ecological-infrastructure or ecosystem-service emphasis, and 25 were not about topical spatial mapping, land-use, or sustainability analysis. Another 25 were excluded due to an ineligible publication type, language, date, or inadequate evidence. Twenty-five unique primary studies remained in the final synthesis. The same eligibility criteria were used at each stage of the screening process, and the decision on exclusion was placed in the screening spreadsheet. Only the studies that were verified in terms of study area, methods, ecological outcome, as well as key findings were included in the final corpus. This created an extensive dataset and still maintained methodological diversity in remote sensing, spatial modelling, ecosystem-service evaluation, habitat analysis, and urban-climate analysis.

Figure 1
PRISMA 2020 flow diagram of study identification, screening, eligibility, and inclusion



Note. Source. Author's elaboration following the PRISMA 2020 reporting framework (Page et al., 2021).

2.5. Data Extraction and Evidence Synthesis

A standardised extraction sheet was made, which noted the author, year of publication, country or region, urban environment, study time, source of data, analysis approach, expansion index, ecological-infrastructure element, sustainability result, key finding of the study, and planning suggestion. The initial extraction was done by one reviewer, and each extracted entry was cross-linked to the entire text by a second reviewer; the remaining

disagreements were resolved by consensus. Direct reporting of numerical results retained original values, and all values were not transformed between different currencies, spatial scales, and ecosystem-service systems since such attempts would result in false comparability. Recent assessments of urban ecosystem-service mapping also indicate high levels of methodological heterogeneity amongst indicator-based, integrated-model, valuation, and scenario approaches (Pereira et al., 2024). The evidence extracted was mapped (initially in a descriptive manner by geography, year, and method) and compared within thematic domains. The complete study-characteristics matrix to be used in the synthesis is given in Table C1.

Deductive and inductive coding were merged with thematic synthesis. Deductive codes were indicative of the review framework: expansion morphology, ecological land conversion, fragmentation and habitat quality, ecosystem-service value, climate regulation, water regulation, provisioning effects, and planning response. In comparison, similar codes were merged into five themes at a higher level that reflected the most prevalent sustainability-cost pathways. It was structured on the principle that the thematic analysis process should render the process of coding decisions, theme delimitation, and interpretive elaboration explicit instead of assuming themes to be self-evident categories (Braun and Clarke, 2021). Different results were held as counter-patterns, especially in instances where urban greening, food supply, or chosen ecosystem services had increased in spite of the general ecological pressure. Appendix E indicates the studies contributing to each theme, convergent findings, differences, and planning implications in the thematic synthesis matrix.

2.6. Methodological Quality Appraisal

A review-specific descriptive appraisal matrix created to conduct spatial urban-ecological studies was used to analyse the quality of the methodology. Six criteria determined whether a study had a clear measure of urban expansion, operationalised an ecological outcome, provided sufficient reports of spatial and temporal data, reported validation or sensitivity tests, described an analytically reproducible approach, and recognised uncertainty or study limitations. The appraisal was done by two reviewers who agreed on the differences by reaching a consensus. Each criterion was rated 2 when fully realised, 1 when partially realised, and 0 when not realised. The total scores of 11-12 were higher methodological completeness, 8-10 moderate completeness, and 0-7 lower completeness. These groups were employed to report methodologically, instead of being a tested risk-of-bias tool or to exclude studies. The focus on validation and transparency was indicative of the same issues found in ecosystem-service mapping reviews (Pereira et al., 2024) and the issue of non-uniform reporting of parameters in quantitative urban ecosystem-service assessment (Ma and Yang, 2025). The study-level appraisal is reported in Table D1.

3. RESULTS

3.1. Characteristics and Methodological Profile of the Evidence

The 25 articles were published between 2016 and 2026, with 20 published in 2021 or later, which explains the rapid increase in empirical evaluation of the cost of the ecological state of the metropolis. The evidence base was not even geographically distributed: 19 studies were done based on the whole or a part of them in the Asian urban systems, five studies were carried out in African settings or a continental pattern, and one was a comparison of European capital metropolitan areas. The most represented was China, then India and Pakistan, and Latin America, North America, and Oceania were also not represented. The standard base was remote sensing and GIS and ecosystem-service valuation, InVEST, landscape metrics, regression, spatial econometrics, cellular automata, Markov modelling, or land-surface-temperature analysis. The study-level settings, periods,

methods, ecological outcomes, and synthesised findings that support these comparisons are presented in Table C1 (Hu & Zhang, 2020; Hysa et al., 2024; Tian et al., 2023).

Descriptive appraisal showed an increase in, or moderate, methodological completeness between the corpus, with no study belonging to the lower category of completeness (Table D1). More robust studies integrated multi-date land-cover classification and reported accuracy, explicit metrics of expansion, validated ecosystem models, sensitivity analysis, or alternative scenarios (Akhtar et al., 2020; Mohammadyari et al., 2023; Wang et al., 2024). The intermediate range of scores was mostly associated with little uncertainty analysis, benefit-transfer assumptions, or ecological outcomes based on land-cover proxies. These limitations limited the ability to directly compare monetary values, habitat indices, and ecosystem-service scores, but conversion trajectories were similar among independent settings. The appraisal thus aided synthesis around convergent mechanisms and direction of effects and not a single standardised effect size (Das & Das, 2019; Kapoor, 2026).

3.2. Metropolitan Expansion and Conversion of Ecological Land

Throughout the corpus, the growth of metropolitanism was more a process of outward conversion of land than a dispassionate expansion of urban density. Tian et al. (2023) discovered edge expansion to be the most common morphology of 13 Chinese urban agglomerations, whereas Li et al. (2021) found edge expansion to be the most common in the Shanghai-Hangzhou Bay area before leapfrog became more influential at larger scales. The conversion pressure was always directed towards ecologically or productively useful land. As the built-up area increased, Guangzhou lost a significant portion of forest and cultivated land, with its forest share decreasing to 25.88% and cultivated land to 12.59% between 1987 and 2017 (He et al., 2021). A similar pattern was observed in Islamabad, with built-up cover growing by 41.7 percentage points and forest and water bodies decreasing (Shah et al., 2021). These examples demonstrate that metropolitan expansion shifts the ecological potentiality of peripheral landscapes to inner-city impervious cover.

The identical conversion process was found in wetlands, green spaces, and vegetation systems, although its scale depended on circumstances. Zhao et al. (2016) reported large-scale changes in wetlands in the Pearl River Estuary, where the natural wetlands conversion went through constructed wetlands and finally urban land. In Kuala Lumpur, Jakarta, and Metro Manila, urban growth had taken over the green space and decreased the green-space area by over 30% over the period of about 25 years, with fragmentation being particularly apparent in Jakarta and Metro Manila (Muhamad Nor et al., 2021). In two independent studies, Lahe et al. (2020) found a 126 percent increase in built-up land between 1990 and 2019, and Akhtar et al. (2026) found a 3-decade reduction in vegetation and a steep increase in built-up area, respectively. The structural relation between the ecological loss and the location of the new metropolitan land was seen across the land classes.

3.3. Fragmentation, Habitat Quality, and Spatial Spillovers

Ecological loss was coupled with a decrease in the integrity of the remaining habitat. Hu and Zhang (2020) discovered that the area of ecological land in Zhuhai had shrunk by 274.8 km², or 32.3, over the period of 1991-2018 and had become increasingly fragmented. This trend was solidified at larger scales by habitat-quality studies. Wu et al. (2021) found that the quality of the habitat in the Pearl River Delta continued to decrease, with the steepest drop observed in 2000-2010, but the adverse impact of urbanisation has been softened by the introduction of ecological policies. According to Xie and Zhu (2023), the area of construction land in Chengdu was growing fast, and the quality of the habitat was worsening and had negative relationships with land-use intensities. Combined, these results illustrate that it is not area loss that measures ecological cost; configuration, connectivity, and proximity to development are the factors that define the extent to which there is functional habitat after urban conversion.

There were also spatial effects that were not limited to the parcels that were turned directly into urban land. Wang et al. (2022) established that urban land in the Chengdu-Chongqing agglomeration grew by 2,890.42 km², or 170.82, between 2000 and 2018, mostly at the cost of farmland and grassland. Their spatial Durbin analysis showed some direct habitat-quality effects and progressively significant spillover effects between neighboring areas. Similar results were demonstrated in a study by Zhang et al. (2026): leapfrog morphology caused considerable losses to multiple ecosystem services in Jinan and Dongying, but edge expansion contributed to considerable loss of food production by occupying farmland. Koloko et al. (2026) offered a view of the area of protection and revealed direct built-up invasion into Table Bay Nature Reserve and increasing pressure at the urban-conservation interface. These findings suggest that discontinuous and fragmented development is capable of exporting ecological costs beyond the direct development footprint.

3.4. Ecosystem-Service Decline and Monetary Sustainability Costs

A consistent result of ecosystem-service valuation studies was to convert land conversion into functional and economic losses, with varying coefficients and units. Das and Das (2019) found that the total ecosystem-service value has decreased by a quarter in Old Malda as the cropland and vegetation shrank, and the soil formation, climate regulation, and nutrient cycling declined significantly. Sharma et al. (2020) estimated significant monetary loss in ecosystem services in Delhi between 1998-2018, and 2018, and forest deterioration represented a significant portion of regulatory and provisioning value. Overall, the total ecosystem-service value in Guangzhou fell by 20.61% between 1987 and 2017, regardless of the change over time, with a shrinking forest and cultivated land (He et al., 2021). A similar trajectory of change was observed in Addis Ababa with three decades of urban growth, where land-use transition diminished the value of ecosystem services and concentrated stress around the fast-growing built-up areas (Hailu et al., 2024). In these cities, loss of ecological lands was recurrently reducing urban natural capacity.

Multi-service experiments indicated that aggregate deterioration may mask significant trade-offs among single functions. The authors discovered that carbon storage, biodiversity protection, the quality of habitats, soil-and-water protection, and water protection across Chinese urban agglomerations had a general downward trend, whereas nutrition delivery ratio and food supply had an upward tendency (Tian et al., 2023). Similarly, Mohammadyari et al. (2023) concluded that business-as-usual growth in a mixed Iranian landscape had a positive effect on water yield and a negative effect on food production and recreation, whereas a protection-based scenario had higher overall service conditions. Wang et al. (2024) found varying relationships among the ecosystem services throughout the Su-Xi-Chang region and indicated that alternative urbanisation routes transformed the relationships of trade-offs and lose-lose. On the metropolitan level, Hysa et al. (2024) reported a tendency of decreasing ecosystem-service potential in the European capitals, showing that the trend was not limited to fast urbanising cities in Asia or Africa. Sustainability cost thus became a portfolio issue and not a uniform depreciation of all the services.

The African evidence also indicated that both degradation and recovery can be contained in the green-space dynamics. Bizuayehu et al. (2025) associated land-cover change in Gondar with significant changes in urban green-space ecosystem-service value, such as a significant decrease in water-body value during the study. Muhoza and Zhou (2025), however, concluded that there was a rapid increase in African urban land in the period between 2000 and 2020 and an improvement in the proportion of urban green space in the later decade in some cities, signifying that urban expansion can be partially counterbalanced by greening interventions without reversing it. This is a counter-pattern between gross metropolitan growth and the ecological design of the same. Present green-

area metrics can thus be misleading with regard to historic ecological degradation or exaggeration. The fact justifies the understanding of sustainability cost by tracking and service structure instead of a one-point measure (Bizuayehu et al., 2025; Muhoza & Zhou, 2025).

3.5. Thermal, Hydrological, and Provisioning Consequences

Thermal analyses were a direct biophysical realisation of the ecological-infrastructure loss. Frimpong et al. (2023) demonstrated that the built-up areas in Accra were transformed into forest and agricultural land and that built-up growth was positively associated with land-surface temperature, as well as negatively with vegetation. A similar process was observed in Sialkot (Javaid et al., 2023), where the conversion of vegetation was accompanied by an increase in mean summer land-surface temperature by about 4.5C and in winter by about 5.7C over 1989-2020. These investigations widen the definition of ecological cost, beyond habitat or monetary worth, by demonstrating the effect of the loss of vegetated surfaces on the urban thermal environment. Due to the potential for increased cooling demand and heat exposure, and because higher surface temperature boosts ecosystem-service valuation in isolation, land-cover transition has infrastructure and public-welfare impacts (Frimpong et al., 2023; Javaid et al., 2023).

Hydrological and provisioning effects were contextual, but were related to the ecological land transformed. Zhao et al. (2016) demonstrated that wetland changes in the Pearl River Estuary decreased the natural wetlands and transformed the ecological protection framework of a swiftly urbanising estuary. Kapoor (2026) observed that ecosystem-service changes across the National Capital Region in India were spatially non-uniform, with more intensive decreases in regulating and supporting services in the more rapidly urbanising districts and less uniform changes in provisioning and cultural services. The pattern isolates two separate processes: growth tends to decrease the quantity or continuity of ecological infrastructure, and individual services can increase or decrease, or move in space, with hydrology, management, and demand. This difference is fundamental to the understanding of the costs of sustainability since the chosen service gains may not necessarily offset the losses in habitat, law, or ecological resilience (Zhao et al., 2016; Kapoor, 2026).

4. DISCUSSION

The synthesis suggests that metropolitan growth is always linked to sustainability expenses in terms of land conversion, fragmentation, and ecological decrease. This builds upon previous syntheses of urban green and blue infrastructure that have not systematised evidence based on the mechanism of growth pressure as a starting point. In their study, Veerkamp et al. (2021) discovered that urban ecosystem-service measures were clustered around temperature control and recreation, and there was a significant difference in indicators and infrastructure categories. The current synthesis demonstrates the importance of this: the loss of habitat and exposure to heat and loss of regulation of water can become interrelated results of the same spatial change. Epie et al. (2026) also found land-use change as a key factor in ecosystem-service change, but their world-systemic review was not confined to urban expansion. The evidence thus introduces a metropolitan pressure-outcome structure specifically to the wider land-change scholarship.

The findings corroborate reviews that consider ecological infrastructure multifunctional and not as estranged green assets. Evans et al. (2022) demonstrated that green infrastructure and urban agriculture offer different types of bundles of provisioning, regulating, cultural, and supporting services. Korkou et al. (2023) also theorised that multifunctionality is based on spatial distribution, network structure, accessibility, and integration in planning. The current review displays the reverse issue, which is that

expansion can eliminate a number of functions once converted land performs habitat, water, food, carbon, and climate-regulation functions. The compensation based on hectares may thus not be sufficient where the replacement green space varies in terms of location, connection, maturity, or ecological utility. Metropolitan sustainability is thus concerned with what is lost of the ecological capacity rather than a question of how much nominal green area is left following development.

The second cross-review implication is that expansion morphology and spatial scale are significant. Pereira et al. (2024) established that urban ecosystem-service mapping uses quantitative metrics and integrated models extensively, whereas comparatively few studies justify model results. Ma and Yang (2025) also discovered that there was a broad range of variation in approaches, equations, and transparency of parameters among quantitative urban ecosystem-service studies. The choice of method can influence the metropolitan cost that is visible: landscape measures show fragmentation, InVEST focuses on service change, valuation monetises transitions, and thermal analysis shows climate impacts. The single approach does not encompass the entire sustainability burden. Convergence of methods across scales and linking parcel conversion to spillovers, service demand, and long-term trajectories of land makes interpretation strongest.

The geographic clustering of evidence is cause to fear. Pereira et al. (2024) indicated that mapping studies were mostly concentrated in Europe and China, and even in South America, Muñoz-Pacheco and Villaseñor (2022) found uneven coverage. The same study by Dushkova et al. (2025) showed that even in highly urbanised and ecologically significant areas, urban ecosystem-service scholarship could be sparse. The focus of this review was particularly in Asia since to be eligible, one had to explicitly specify an expansion-ecology nexus and no study in Latin America survived in the final corpus. The mechanisms that are observed are not global estimations of the magnitude of effects but are conducted across different cities. Similar longitudinal studies are required in Latin America, North America, Oceania, and the less represented African metropolitan areas to examine how governance and ecological setting alter these associations.

In practice, ecological infrastructure must be part of metropolitan growth management as a functional infrastructure with quantifiable service levels. The planning authorities will be able to map forests, wetlands, water bodies, productive land, habitat corridors and urban green networks first, before assigning areas of expansion. Growth scenarios ought to contrast developable land and transport efficiency and quality of habitats, control over carbon storage, water management, thermal exposure, and food-production capacity. Jato-Espino et al. (2023) suggest geoprocessing and multi-criteria models to consider various green-infrastructure services, whereas Herath and Bai (2024) note the importance of considering green infrastructure as a part of larger sustainability goals. Sustainable infrastructure and green innovation can support development strategies that balance economic growth with broader sustainability objectives (Alqahtani, 2025). Spatial planning should also consider geomorphological characteristics and environmental constraints when identifying suitable areas for future development (Utama & Mulyasari, 2024). The emphasis should be on context-based small-scale development, ecological-corridor conservation, the reconstruction of damaged blue-green systems, and leapfrog development should be avoided in sensitive landscapes. Baseline maps should be maintained through monitoring to enable comparison of the gains in claimed greening with historical ecological losses.

These conclusions have a number of limitations. The search was limited to peer-reviewed, open-access, English-language journal articles; this could have omitted any local studies, planning reports, and research behind subscriptions. The 2016-2026 window enhanced the contemporary relevance, but failed to notice previous studies that might explain longer historical trends. Three databases were searched, and indexing differences between databases might have influenced retrieval even with conceptually similar search strings. The methodological heterogeneity did not allow meta-analysis, as the studies

reported in different spatial units, service frameworks, monetary coefficients, habitat indices, and temperature results. Urban ecosystem service reviews have recognised the same issues of inconsistency of indicators and low validation, which diminish the direct comparability of studies (Ma & Yang, 2025). Lastly, the generalisation in the world is restricted by concentration in Asian cities. These limitations render the review most powerful as a synthesis of repeated mechanisms and planning implications and not a cumulative estimate of overall effect magnitude.

5. CONCLUSIONS

This systematic review indicates that a regular series of ecological land transformation, fragmentation, and loss of functional capacity is always linked to metropolitan growth. In the 25 main studies, outward, edge, and leapfrog expansion time and again supplanted forests, wetlands, cultivated land, urban green space, habitat, and other ecologically viable surfaces. These correlative physical transformations were linked to poorer habitat quality, diminished ecosystem-service quality, diminished carbon and water regulation, increased land-surface temperature, and losses in selected provisioning services. The evidence thus indicates that the environmental cost of metropolitan growth cannot be in the form of built-up area alone.

Significant variation is also observed in the synthesis. There was no even distribution of loss of individual ecosystem services, and some cities had an improvement in food supply, water yield, or urban greening later on. The form of expansion, regional ecology, planning policy, and baseline land cover determined how growth resulted in focused, diffuse, or partially alleviated costs. This diversity reinforces and does not undermine the main achievement since it shows that the planning decisions influence the ecological results in metropolitan areas.

To have sustainable metropolitan development, ecological infrastructure must be taken as functional infrastructure prior to land being allocated to expansion. Growth policies must safeguard interrelated ecological systems, contrast the alternative developmental forms, measure the loss of services and the economic gains, and track the cumulative change with the past benchmarks. There is a need to expand similar longitudinal designs to underrepresented areas in future studies and enhance validation across ecosystem-service models. The main contribution of the review is a complete evidence chain between metropolitan growth and ecological-infrastructure loss and subsequently ecological sustainability cost, which offers a more definite framework on which the planning decisions can be made so as to balance urban development with ecological capacity.

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Author contributions. Abdallah Bakhit Saleh was responsible for conceptualisation, methodology, investigation, data curation, formal analysis, interpretation, and preparation of the manuscript.

Data availability. The review used published open-access studies. The screening counts, study-characteristics matrix, methodological appraisal matrix, and thematic synthesis matrix are reported in the appendices to support transparency and reproducibility.

Gender considerations. The review did not involve human participant data, and sex- or gender-based variables were not applicable to the environmental-geography research question.

Ethics statement. Ethical approval was not required because the review analysed previously published studies and did not involve new research with human participants, animals, or identifiable personal data.

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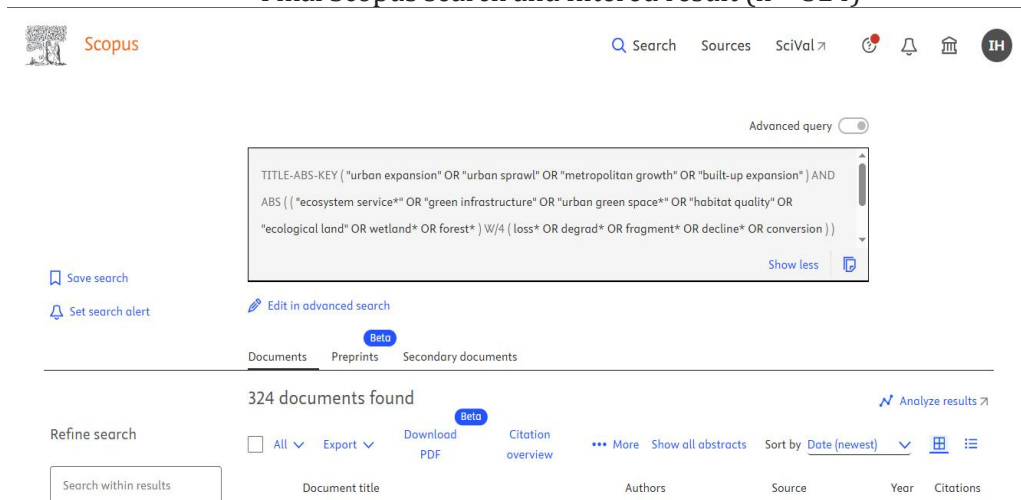
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Appendix A. Database Search Screenshots

Figure A1

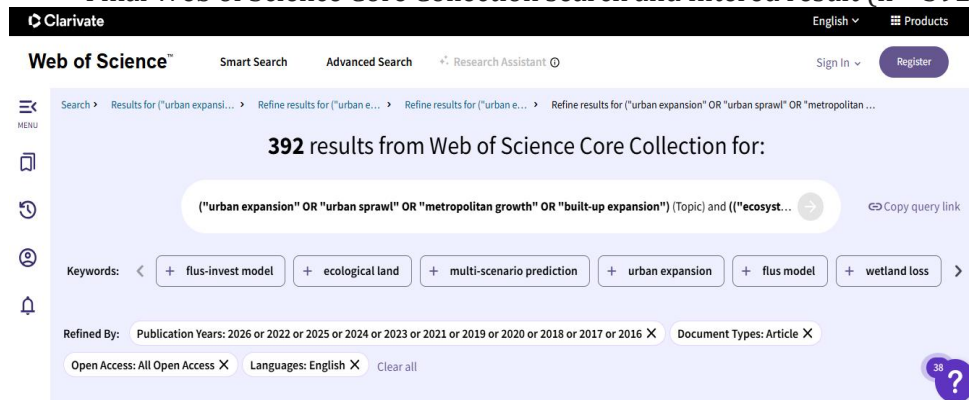
Final Scopus search and filtered result (n = 324)



Note. Source. Database search covering publications from 2016 to 2026.

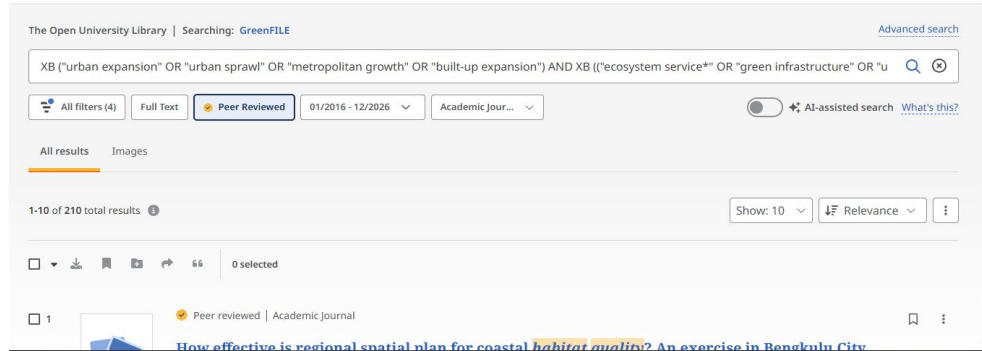
Figure A2

Final Web of Science Core Collection search and filtered result (n = 392)



Note. Source. Database search covering publications from 2016 to 2026.

Figure A3
Final GreenFILE (EBSCOhost) search and filtered result (n = 210)



Note. Source. Database search covering publications from 2016 to 2026.

Appendix B. PRISMA Screening Record

Table B1

Study screening and eligibility decisions

Stage	Count / reason
Records identified	926 (Scopus 324; Web of Science 392; GreenFILE 210)
Duplicates removed	126
Records screened	800
Records excluded at title/abstract	650
Reports sought for retrieval	150
Reports not retrieved	10
Reports assessed for eligibility	140
Full-text exclusions	115 total
Exclusion reason 1	Not focused on urban expansion or metropolitan growth (n = 35)
Exclusion reason 2	No focus on ecological infrastructure or ecosystem services (n = 30)
Exclusion reason 3	No relevant spatial mapping, land-use, or sustainability analysis (n = 25)
Exclusion reason 4	Ineligible publication type, language, date, or insufficient evidence (n = 25)
Studies included	25

Note. Counts reproduce the PRISMA flow shown in Figure 1; full-text exclusion reasons sum to 115. Source. Author's screening record.

Appendix C. Characteristics of Included Studies

Table C1

Summary of the 25 primary studies included in the systematic review

ID	Study	Setting / period	Design / data	Ecological outcome	Key synthesized finding
S1	Zhao et al. (2016)	Pearl River Estuary, China; 1979-2009	Landsat; wetland transition/intensity analysis	Natural/constructed wetlands	Approximately one-third of wetland area was lost; natural wetlands were progressively converted through constructed wetland to urban land.
S2	Das & Das (2019)	Old Malda, India; 1990-2017	Remote sensing, GIS, benefit-transfer ESV, sensitivity analysis	Cropland and vegetation; ecosystem services	Built-up land rose 47.64%; total ESV fell 25%, with strong declines in soil formation, climate regulation, and nutrient cycling.
S3	Sharma et al. (2020)	Delhi, India; 1998-2018	Satellite LULC, benefit-transfer ESV, sensitivity analysis	Forest and natural/semi-natural land	Urbanization reduced ecosystem-service value; forest loss accounted for a major share of lost regulating and provisioning value.
S4	Akhtar et al. (2020)	Lahore, Pakistan; 1990-2019 plus 2030/2050 scenarios	Remote sensing, CA-Markov, ESV valuation	Vegetation, water, cultivated/ecological land	Built-up land increased 126%; vegetation declined, and environmental-sustainability scenarios retained more ESV than rapid-growth pathways.
S5	Hu & Zhang (2020)	Zhuhai, China; 1991-2018	Transition matrix, landscape indices, logistic regression	Urban ecological land	Ecological land declined 274.8 km ² (32.3%) and became more fragmented; proximity to built-up land strongly influenced conversion.
S6	He et al. (2021)	Guangzhou, China; 1987-2017	Landsat classification, ESV estimation, driver analysis	Forest, cultivated land, water; ecosystem services	Forest and cultivated land shares fell sharply; total ESV declined 20.61%.
S7	Wu et al. (2021)	Pearl River Delta, China; 1990-2018	Habitat-quality modelling, urbanization index, spatial analysis	Habitat quality	Habitat quality declined with sprawl, especially in 2000-2010; later policy implementation moderated the negative urbanization effect.
S8	Li et al. (2021)	Shanghai-Hangzhou Bay, China; 1990-2019	Expansion-form metrics, ecosystem-service modelling, regression	Food supply, carbon, habitat quality, soil retention	Edge expansion dominated early growth; leapfrog expansion became increasingly influential, while all expansion forms produced negative ecosystem-service effects.
S9	Muhamad Nor et al. (2021)	Kuala Lumpur, Jakarta, Metro Manila; approx. 25-year period	Satellite LULC and landscape metrics	Urban green space	Built-up areas encroached on green space in all three cities, reducing green space by more than 30% and increasing fragmentation.

ID	Study	Setting / period	Design / data	Ecological outcome	Key synthesized finding
S10	Shah et al. (2021)	Islamabad, Pakistan; 1979-2019	Multi-date Landsat, supervised classification	Forest and water bodies	Built-up land expanded strongly while forest declined 9.03% and water bodies 1.21%.
S11	Wang et al. (2022)	Chengdu-Chongqing, China; 2000-2018	Remote sensing, bivariate spatial autocorrelation, Spatial Durbin model	Habitat quality	Urban land increased 2,890.42 km ² (170.82%); direct and spillover effects contributed to habitat-quality decline.
S12	Frimpong et al. (2023)	Accra, Ghana; 1986-2022	Random Forest LULC, LST, regression	Forest/agricultural land; thermal regulation	Conversion to built-up land increased LST; vegetation showed an inverse relationship with temperature.
S13	Javaid et al. (2023)	Sialkot, Pakistan; 1989-2020 plus 2030 projection	Landsat, LST, CA-Markov	Vegetation and thermal environment	Vegetation declined as built-up land increased; mean LST rose about 4.5°C in summer and 5.7°C in winter.
S14	Xie & Zhu (2023)	Chengdu, China; 2000-2020	InVEST habitat quality and land-use intensity analysis	Habitat quality	Construction land expanded rapidly; habitat quality declined and was negatively associated with land-use intensity.
S15	Mohammadyari et al. (2023)	Karaj mixed urban-natural landscape, Iran; scenario analysis	Markov-ANN, MOLA, InVEST/scenario modelling	Water yield, food production, recreation	Business-as-usual expansion increased water yield but reduced food and recreation; protection-based planning improved the service bundle.
S16	Tian et al. (2023)	13 urban agglomerations, China; 2000-2020	GlobeLand30, expansion indices, InVEST, hotspot/correlation analysis	Seven ecosystem services	Edge expansion dominated; carbon, biodiversity, habitat, soil/water conservation, and water conservation declined, while food supply and NDR increased.
S17	Hailu et al. (2024)	Addis Ababa, Ethiopia; 1993-2023	Satellite GIS, benefit-transfer ESV, AHP	Ecosystem-service value	Built-up expansion converted ecological land and reduced ecosystem-service value, with pressure concentrated around fast-growing urban zones.
S18	Hysa et al. (2024)	38 European capital metropolitan areas	Land-cover change and ecosystem-service potential assessment	Metropolitan ecosystem-service potential	Ecosystem-service potential declined across the metropolitan sample, showing that losses also occur in mature European urban systems.
S19	Wang et al. (2024)	Su-Xi-Chang, China; 1990-2020 plus 2050 scenarios	Urbanization scenarios and ecosystem-service modelling	Multiple ecosystem services	Urbanization changed service trade-offs and synergies; alternative scenarios produced materially different future service outcomes.

ID	Study	Setting / period	Design / data	Ecological outcome	Key synthesized finding
S20	Bizuayehu et al. (2025)	Gondar, Ethiopia; 1991-2024	Remote sensing, GIS, ESV and expansion metrics	Urban green space and water-related services	Land-cover change substantially altered green-space ESV, including a pronounced decline in water-body contribution.
S21	Muhoza & Zhou (2025)	African urban areas; 2000-2020	Continental remote-sensing analysis	Urban green space	Urban area expanded rapidly; later-period green-space gains in some cities partly offset earlier decline but did not reverse overall urban expansion.
S22	Kapoor (2026)	National Capital Region, India; 2005-2025	Remote sensing/LULC and benefit-transfer ESV	Regulating, supporting, provisioning, cultural services	Regulating and supporting services declined strongly in rapidly urbanizing districts; provisioning and cultural patterns were more mixed.
S23	Adnan et al. (2026)	Lahore, Pakistan; 1993-2023	Google Earth Engine, Landsat, NDVI/NDBI	Vegetation cover	Vegetation declined markedly while built-up area increased, although localized later-period vegetation recovery occurred.
S24	Zhang et al. (2026)	Jinan and Dongying, China	Expansion pattern analysis and InVEST ecosystem services	Carbon, water yield, food, habitat, soil retention	Edge expansion dominated; leapfrog growth caused severe multi-service losses, while edge expansion drove major food-production loss through farmland occupation.
S25	Koloko et al. (2026)	Table Bay Nature Reserve, South Africa; 2000-2024	Multi-temporal remote sensing	Protected ecological land/habitat	New built-up land directly encroached on the reserve, intensifying pressure along the urban-protected-area interface.

Note. ESV = ecosystem-service value; LULC = land use/land cover; LST = land-surface temperature.

Findings are condensed from the included full texts. Source. Author's synthesis of the 25 included studies.

Appendix D. Methodological Quality Appraisal

Table D1

Methodological-completeness appraisal matrix for included studies

Study	Q1	Q2	Q3	Q4	Q5	Q6	Score	Completeness
S1	2	2	2	2	2	1	11	Higher
S2	2	2	2	2	2	1	11	Higher
S3	2	2	2	2	2	1	11	Higher
S4	2	2	2	2	2	2	12	Higher
S5	2	2	2	1	2	1	10	Moderate
S6	2	2	2	2	2	1	11	Higher
S7	2	2	2	1	2	1	10	Moderate
S8	2	2	2	1	2	1	10	Moderate
S9	2	2	2	2	2	1	11	Higher
S10	2	1	2	2	2	1	10	Moderate

Study	Q1	Q2	Q3	Q4	Q5	Q6	Score	Completeness
S11	2	2	2	1	2	1	10	Moderate
S12	2	1	2	2	2	1	10	Moderate
S13	2	1	2	2	2	1	10	Moderate
S14	2	2	2	1	2	1	10	Moderate
S15	2	2	2	2	2	2	12	Higher
S16	2	2	2	2	2	1	11	Higher
S17	2	2	2	2	2	1	11	Higher
S18	1	2	2	2	2	2	11	Higher
S19	2	2	2	2	2	2	12	Higher
S20	2	2	2	1	2	1	10	Moderate
S21	2	2	2	2	2	1	11	Higher
S22	2	2	2	1	2	1	10	Moderate
S23	2	1	2	2	2	1	10	Moderate
S24	2	2	2	2	2	1	11	Higher
S25	2	1	2	2	2	1	10	Moderate

Note. Q1 = urban expansion quantified; Q2 = ecological outcome operationalized; Q3 = spatial/temporal data adequately reported; Q4 = validation, accuracy, or sensitivity addressed; Q5 = analytical method reproducible; Q6 = uncertainty/limitations acknowledged. Scoring: 2 = fully met, 1 = partly met, 0 = not evident. Higher completeness = 11-12; Moderate completeness = 8-10; Lower completeness = 0-7. Categories summarize reporting completeness and are not a validated risk-of-bias scale. Source. Author's appraisal of the 25 included studies.

Appendix E. Thematic Synthesis Matrix

Table E1

Cross-study thematic synthesis of metropolitan ecological costs

Theme	Operational synthesis	Contributing studies	Convergent pattern	Important variation / counter-pattern	Planning implication
1. Ecological land conversion	Built-up growth replacing wetland, forest, vegetation, cultivated land, green space, or ecological land	S1-S6, S9-S10, S12-S13, S17, S20-S23, S25	Expansion repeatedly reallocates ecologically functional land to impervious or urban uses.	Later greening or agricultural expansion can coexist with earlier losses; land categories differ among regions.	Protect high-function ecological land before zoning new urban growth and retain historical baselines.
2. Fragmentation and habitat degradation	Loss of connectivity, increased patch isolation, declining habitat quality, spillovers	S5, S7-S8, S11, S14, S16, S24-S25	Ecological cost extends beyond area loss because configuration and neighboring development affect habitat function.	Policy intervention moderated habitat decline in some settings; expansion morphology changes severity.	Use ecological-network and corridor criteria alongside simple green-area targets.
3. Ecosystem-service and natural-capital loss	Changes in ESV, carbon, water, soil, biodiversity, recreation, food, and related functions	S2-S4, S6, S8, S15-S22, S24	Most studies report declining aggregate or regulating/supporting services as urban land expands.	Food supply, water yield, or selected cultural/provisioning services can increase, creating trade-offs.	Evaluate service bundles and avoid treating one service gain as compensation for broader functional decline.

Theme	Operational synthesis	Contributing studies	Convergent pattern	Important variation / counter-pattern	Planning implication
4. Thermal and hydrological costs	Higher LST, wetland conversion, reduced water conservation, runoff/water-quality pressures	S1, S12-S13, S16, S22	Loss of vegetation and wetland functions increases thermal and hydrological stress.	Magnitude depends on climate, imperviousness, drainage, and regional water conditions.	Integrate blue-green infrastructure, heat mitigation, and watershed functions into metropolitan growth scenarios.
5. Expansion morphology and cumulative effects	Edge, leapfrog, outlying, infill, direct and spillover effects	S7-S8, S11, S16, S19, S24-S25	Discontinuous and peripheral expansion can intensify fragmentation and export impacts beyond converted parcels.	Compact or protection-oriented scenarios can reduce some losses, but outcomes remain context dependent.	Compare alternative spatial growth forms using ecological-service and habitat metrics before approving expansion.
6. Mitigation, recovery, and governance	Greening, protection scenarios, ecological policies, restoration, growth management	S4, S7, S15, S19, S21, S23	Policy and restoration can moderate losses or improve selected services despite continuing urban growth.	Greening gains may not restore historical connectivity or replace lost mature ecosystems.	Track net ecological change over time and combine growth controls with restoration and service-performance targets.

Note. Study identifiers correspond to Table C1. Themes preserve both convergent findings and counter-patterns to avoid treating urban ecological outcomes as uniform. Source. Author's thematic synthesis of the included studies.