



Research article

Assessing ecological impacts of urban forest conversion using Sentinel-2 NDVI-based canopy cover analysis: A systematic review and bibliometric analysis

Norliana Mokhtar^a, Siti Aekbal Salleh^{a,b,*}, Siti Khairiyyah Mohd Hatta^{b,c}, Faezah Pardi^{b,c}, Nabilah Naharudin^a, Zenaida Baoanan^d, Rahmawaty^e

^a Faculty of Built Environment, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor 40450, Malaysia

^b Institute for Biodiversity and Sustainable Development (IBSD), Universiti Teknologi MARA, Shah Alam, Selangor 40450, Malaysia

^c Faculty of Applied Science, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor 40450, Malaysia

^d Department of Biology, College of Science, University of the Philippines Baguio, Baguio City 2600, Philippines

^e Faculty of Forestry, Universitas Sumatera Utara, Deli Serdang, North Sumatra 20155, Indonesia

Article Info

Article history:

Received 25 September 2025

Revised 6 May 2026

Accepted 5 June 2026

Available online 15 July 2026

Keywords:

Canopy cover analysis,

GIS,

Remote sensing,

Systematic review,

Urban forest conversion

Abstract

Importance of the work: The lack of integration of canopy cover assessment with ecological indicators constrains effective monitoring and conservation of small tropical urban forests.

Objectives: To identify research trends, evaluate geographic information system and remote-sensing techniques for canopy cover assessment and determine relevant ecological indicators for the Shah Alam Community Forest (SACF), Selangor, Malaysia.

Materials and Methods: A systematic review was undertaken using: Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) on Scopus-indexed studies (2020–2025); bibliometric analysis via VOSviewer; and inclusion criteria limited to peer-reviewed English articles on urban forest conversion, canopy cover, GIS and remote sensing.

Results: From 1,697 initial records, 465 passed screening and 15 studies underwent full analysis. Research growth peaked in 2024 (110 articles). Four thematic clusters emerged: remote sensing methods, urban forest ecology, canopy change/land use/land cover and conservation policy. China ranked 1st, with Malaysia ranking 10th in publication output. Major gaps were: limited integration of canopy metrics with biodiversity data; few studies on small-scale tropical forests such as SACF; and minimal fragmentation analysis in urban contexts.

Main finding: The conceptual framework of urban forest research, the key research milestones of the Urban Forest Ecological Assessment; the gaps analysis and justification that calls for the research; and the framework for preserving urban forest with geospatial methods that enable the multidimensional canopy cover analysis with ecological indicators can enhance monitoring and conservation strategies for small tropical urban forests.

* Corresponding author.

E-mail address: aekbal@uitm.edu.my (S.A. Salleh)

online 2452-316X print 2468-1458/Copyright © 2026. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>), production and hosting by Kasetsart University Research and Development Institute on behalf of Kasetsart University.

<https://doi.org/10.34044/j.anres.2026.60.4.14>

Introduction

Urban forests serve as vital elements of urban ecosystems, delivering benefits such as biodiversity preservation, carbon storage, microclimate management and cultural enrichment for city inhabitants (Nor et al., 2021). Worldwide, the fast-paced proliferation of metropolitan zones has escalated the demand pressure on these green environments, causing deforestation, separation of ecosystems and a fall in ecological integrity. In tropical areas, including Malaysia, these issues are especially evident owing to their important biodiversity and the quick shifts in land use (Danneck et al., 2023).

The Shah Alam Community Forest (SACF), a remaining lowland dipterocarp ecosystem nestled in Selangor, Malaysia, confronts escalating challenges from urban encroachment and infrastructure expansion (Shah Alam Community Forest Society, 2020). Recognized as a biodiversity hotspot and crucial ecological buffer, SACF is instrumental in sustaining species diversity and ecosystem services for the neighboring urban communities (Urbanice Malaysia, 2022). Conversely, the steady alteration of the earth has brought about a noticeable reduction in canopy cover, which is a crucial metric for assessing habitat quality and ecological robustness.

Geographic information system (GIS) along with remote sensing technologies function as robust mechanisms for tracking these alterations (Shahtahmassebi et al., 2021). Data gathered by Sentinel-2 satellites play a crucial role in the assessment of vegetation indices, including the normalized difference vegetation index (NDVI) and help in recognizing transitions in land use/land cover (LULC) with impressive spatial and temporal resolution. Through the combination of these datasets alongside biodiversity metrics, such as butterflies acting as bioindicators, can acquire a better understanding of the ecological impacts linked to urban forest transformation (Lin et al., 2025).

Butterfly populations are vital bioindicators of urban landscape changes because of their sensitivity to environmental factors such as temperature, humidity and floral availability (Chowdhury et al., 2023). Habitat alterations disrupt ecological connectivity, restricting the organism's ability to thrive in transformed environments (Sushmita et al., 2022). Furthermore Porath and Aranda (2020) emphasized the role of frugivorous butterflies as indicators of habitat quality, underscoring how urban fragmentation affects butterfly populations and, in turn, local biodiversity.

Despite the growing focus on urban forest monitoring in

tropical environments, research that specifically investigates the ecological integrity of SACF is still scarce. Consequently, the current study aimed: 1) to identify international research trends regarding urban forest conversion and its ecological impacts; 2) to assess GIS and remote sensing techniques for analyzing canopy cover; and 3) to ascertain applicable ecological indicators for SACF through bibliometric mapping and systematic review.

Materials and Methods

A comprehensive literature review was undertaken to identify, select and evaluate pertinent research regarding the ecological consequences of urban forest conversion, particularly concentrating on canopy cover analysis through the application of GIS and remote sensing technologies. This analytical technique was based on a coherent structure for sorting, scrutinizing, clarifying and merging results from multiple references within this sphere. By sticking to well-defined review frameworks, the intent of these analyses was to bring together all current research while acknowledging the ecological repercussions, observation techniques and evaluation methods associated with urban forest alteration and biodiversity analysis.

The Scopus database was used to undertake a thorough exploration strategy for relevant literature. Chosen keywords were utilized, such as urban forest alteration, canopy coverage area, geographic information technology, remote sensing data, Sentinel-2 satellite and biodiversity assessments, while also streamlining the literature review to 2020–2025. The parameters for selection were centered on journal papers that had received peer review and on conference documents published in English that were associated clearly with the changes in urban forest ecosystems, the evaluation of canopy density and the examination of ecological outcomes.

The analysis applied the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) approach directed at examining and selecting articles, involving four fundamental stages: identification; screening; eligibility evaluation; and inclusion. Initially, 1,697 scholarly articles were obtained and evaluated in terms of relevance and quality criteria, yielding 465 articles chosen for detailed review. Following the application of the final selection criteria, 15 articles were included for the synthesis of research gaps and bibliometric mapping.

The analysis of trends, associations and thematic

arrangements detected in the chosen research materials was undertaken using the bibliometric application VOSviewer version 1.6.20 (Van Eck and Waltman, 2010). Network visualization was implemented to identify research trends and the links among keywords, alongside density visualization to emphasize critical focal points. This analytical approach delivered enriched insights into the evolution of research in this sector and the incorporation of geospatial tools in measuring the effects of urban forest alteration. Fig. 1 presents the systematic review workflow, detailing the methodology applied to ensure a structured research process.

Scopus database search

A systematic literature search was conducted using the Scopus search engine for studies published between 2020 and 2025, utilizing the search term combinations: TITLE-ABS-KEY ("urban forest conversion") AND TITLE-ABS-KEY ("canopy cover") AND TITLE-ABS-KEY ("GIS" OR "Satellite data"). The queries used Boolean operators, such as AND and OR, to combine keywords, to include synonyms and to refine the scope. Fig. 2 shows the search query syntax applied in Scopus, which also incorporated language filters, document type restrictions and subject area exclusions to ensure that only the most relevant literature items were retrieved.

Inclusion and exclusion criteria

The systematic review was based on explicit inclusion and exclusion criteria to assure quality, relevance and consistency of methods among the reviewed studies. Only full-text journal articles were included, while search results retrieved in other formats (conference abstracts and reviews) were discarded to ensure the quality and evidentiary strength of the database. Furthermore, studies were restricted to English-language articles published between 2020 and 2025. The time limitation was imposed to represent recent methodological evolution in canopy cover measurement and urban forest conversion examination, especially those based on current satellite-based and GIS methodologies. Notably, focusing on this period improved comparability across studies performed under analogous technological and urbanization settings, which is particularly important for rapidly urbanizing tropical environments.

A comprehensive summary of the inclusion and exclusion criteria is provided in Table 1.

Ethics statements

No human, animal or biosafety experimental works were involved.

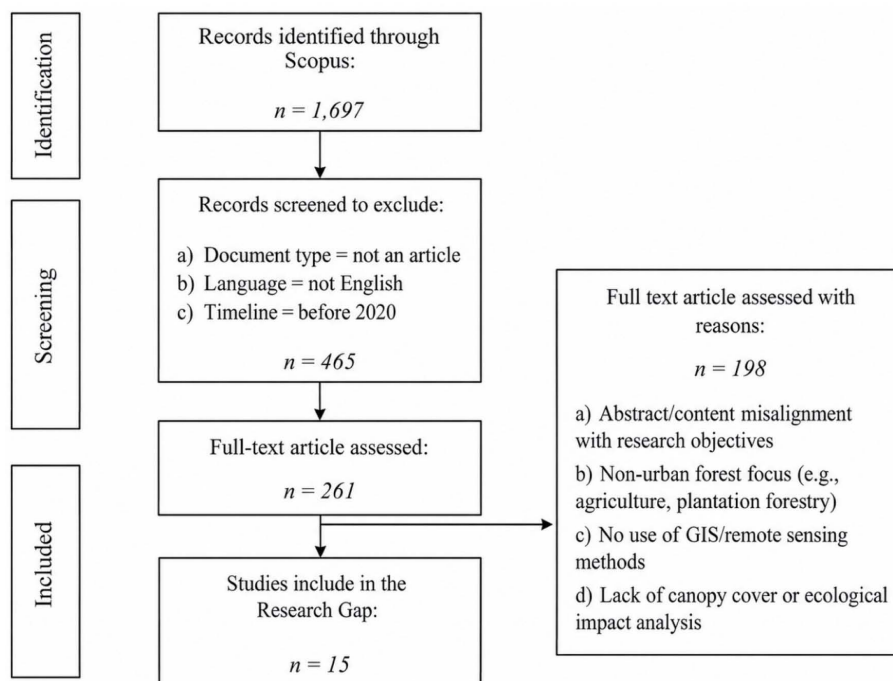


Fig. 1 Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) approach adopted for systematic literature review.

Table 1 Criteria used for the systematic literature review

Criteria	Inclusion	Exclusion
Document type	Article	Conference paper, book chapter, review, conference review, book, note, editorial, data paper
Language	English	Chinese, Italian, German, Indonesian, Persian, Hindi
Timeline	2020–2025	<2020

at the time of the study. Nonetheless, the steady increase in publications from 2020 to 2024 underscored a growing scholarly interest in applying geospatial techniques to evaluate the ecological repercussions of forest conversion, closely aligning with the aims of this SACF-focused investigation.

Fig. 3 depicts the volume of published documents from 2020 to 2025 concerning urban forest conversion, canopy

Keywords
TITLE-ABS-KEY ("urban forest conversion") AND TITLE-ABS-KEY ("canopy cover") AND TITLE-ABS-KEY ("GIS" OR "Satellite data") AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (EXCLUDE (LANGUAGE, "Chinese") OR EXCLUDE (LANGUAGE, "Italian") OR EXCLUDE (LANGUAGE, "German") OR EXCLUDE (LANGUAGE, "Indonesian") OR EXCLUDE (LANGUAGE, "Persian") OR EXCLUDE (LANGUAGE, "Hindi") AND (EXCLUDE (DOCTYPE, "cp") OR EXCLUDE (DOCTYPE, "ch") OR EXCLUDE (DOCTYPE, "re") OR EXCLUDE (DOCTYPE, "cr") OR EXCLUDE (DOCTYPE, "bk") OR EXCLUDE (DOCTYPE, "no") OR EXCLUDE (DOCTYPE, "ed") OR EXCLUDE (DOCTYPE, "dp") AND EXCLUDE (SUBJAREA, "AGRI") OR EXCLUDE (SUBJAREA, "ENER") OR EXCLUDE (SUBJAREA, "BIOC") OR EXCLUDE (SUBJAREA, "ARTS") OR EXCLUDE (SUBJAREA, "IMMU") OR EXCLUDE (SUBJAREA, "MATH") OR EXCLUDE (SUBJAREA, "MATE") OR EXCLUDE (SUBJAREA, "CENG") OR EXCLUDE (SUBJAREA, "CHEM") OR EXCLUDE (SUBJAREA, "ECON") OR EXCLUDE (SUBJAREA, "MEDI") OR EXCLUDE (SUBJAREA, "DECI") OR EXCLUDE (SUBJAREA, "BUSI") OR EXCLUDE (SUBJAREA, "PHYS") OR EXCLUDE (SUBJAREA, "SOCI")

Fig. 2 Image of keywords and exclusion criteria from Scopus search engine queries

Results

Literature development trends

From 2020 to 2025, there was a steady upward trajectory in the volume of publications concerning urban forest conversion, canopy cover assessment and the utilization of GIS and remote sensing in ecological evaluations. In 2020, 58 papers were issued, increasing to 64 in 2021, advancing to 73 in 2022 and achieving 77 in 2023, ultimately culminating at a record high of 110 in 2024. This upsurge signified the escalating international worry concerning the ecological impacts of urban tree depletion, notably in areas facing swift urbanization.

Several factors may account for this trend: the rising urgency to tackle biodiversity decline in urban environments; advancements in satellite imagery, including Sentinel-2; and improved analytical methods for canopy monitoring utilizing NDVI and LULC classification. In addition, the escalation of research outputs might have been affected by initiatives bolstering the development of urban parks and the safeguarding of forests.

In 2025, the number of published articles dropped, with only 83 documents listed, perhaps tied to insufficient data gathering, since the data collection was not for the full year

cover analysis and the utilization of GIS and remote sensing in ecological evaluations. These data highlighted a prominent upward trend in publications spanning 2020 through 2024, succeeded by a considerable fall in 2025. In 2020, the count of published documents stood at 58, which climbed to 64 the following year, then 73 in 2022 and finally 77 in 2023. The total reached a high of 110 in 2024, reflecting a substantial increase in research interest and academic output within this field. Nevertheless, in 2025, the publication count fell to 83, a reduction likely attributable to not representing the full year, so that not all relevant articles finally published for 2025 were

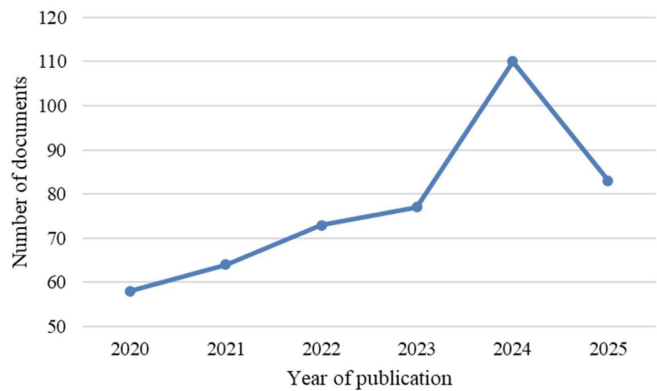


Fig. 3 Number of documents by year extracted from Scopus database (only part of year for 2025).

included.

The graph emphasizes this conclusion, revealing a consistent upward trend in publications over the years, culminating in a high in 2024, the most recent full year in the current analysis. This pattern indicates that scholarly and scientific focus on urban forest conservation and canopy monitoring has been growing, especially in recent years.

Geographical distributions

Table 2 showcases the substantial input from Malaysia, China, Australia, the USA and the UK, demonstrating the discrepancies in research focuses, funding avenues and the extent of geospatial technology integration within these countries. Research outputs differed based on regional contexts; for example, frequently, Malaysia's publications concentrated on specific case studies, such as SACF and various urban green spaces, with the objective of enhancing conservation efforts and urban planning policies. China has allocated substantial resources for extensive environmental monitoring utilizing high-resolution satellite imagery, whereas Australia and the USA regularly utilize sophisticated remote sensing analytics for assessing biodiversity and canopy health. Often, the research conducted in the UK is intertwined with strategies for urban planning and climate resilience.

Network visualization and analyzing bibliometric networks

Network visualization has proven to be a powerful tool for bibliometric analysis, providing graphical representations of the interrelations among authors, citations, keywords and other crucial elements within a bibliometric dataset. This system supports the discovery of thematic divisions, boosts grasp of

keyword links and permits the tracking of developing research movements, delivering crucial understandings about the fluid nature of a certain area. The network visualization map in Fig. 4, crafted using VOSviewer, highlights the interrelated characteristics of keywords associated with urban forest conversion, canopy coverage analysis and practices in GIS and remote sensing.

Within the visual layout, every point denotes a crucial concept and the lines intertwining them reveal their shared existence in one research endeavor. Each node's prominence is connected to how often it occurs and the thickness of the links reveals the solidity of the relationship between two concepts. Through the use of color-coded clusters, keywords sharing strong connections are sorted into clear thematic categories, reflecting the collaborative spirit of research in this discipline.

The examination of co-occurring keywords revealed 104 items divided into four major clusters, each corresponding to a specific thematic emphasis: 1) remote sensing and geospatial analysis, marked by terms such as "GIS," "remote sensing," "Sentinel-2," and "NDVI,"; 2) urban forest ecology and biodiversity, encompassing terms such as "urban forest," "biodiversity," and "habitat loss,"; 3) canopy cover change and LULC dynamics featuring keywords such as "canopy cover," "LULC," "land use change," and "forest fragmentation,"; and 4) conservation and policy frameworks, incorporating terms such as "urban planning," "sustainable development," and "forest conservation."

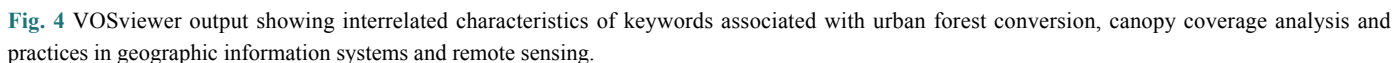
Key terms, such as "urban forest," "canopy cover," and "GIS", have considerable importance within the network, highlighting their crucial role in the current literature. For example, "canopy cover" was closely associated with "biodiversity," "NDVI," and "LULC classification," illustrating the reliance on spectral indices and classification techniques for ecological assessment. In short, 'urban forest' was fundamentally related to 'ecosystem services' and 'habitat fragmentation', reinforcing the essential ecological functions that modern urban forests, including SACF, achieve.

Additionally, the configuration of the network revealed a pronounced methodological emphasis on satellite imagery, particularly Sentinel-2, alongside spatial analysis techniques to monitor canopy loss over time. The amplification of educational importance was correlated with the assessment of tree canopy disparities, illuminating their ecological influences and devising metropolitan preservation tactics.

In essence, the evaluation of network visualizations recognized four main research pathways, stressing the indispensable importance of aligning high-resolution

Table 2 Distribution of identified scholarly articles

Ranking	Country	Frequency
1	China	96
2	USA	81
3	India	45
4	Australia	27
5	Germany	25
6	Indonesia	23
7	UK	22
8	Italy	21
9	Iran	16
10	Malaysia	16



Density visualization and bibliometric network analysis

In the current study, keywords related to urban forest conversion, canopy cover change and ecological assessment using geospatial methods were analyzed based on co-occurrence mapping in VOSviewer. The density map uses a

The current analysis revealed that terms, such as “urban forest”, “canopy cover”, “GIS” and “remote sensing”, dominated the network, indicating their central role in the literature. These terms were closely associated with methodological keywords such as “NDVI”, “Sentinel-2” and “LULC classification”, reflecting the widespread use of vegetation indices and land use mapping techniques to monitor canopy loss.

In addition, the density visualization revealed methodological clusters, where remote sensing techniques intersected with spatial modelling for change detection. This

indicated that often, research in the field combined satellite-based vegetation analysis with GIS-based spatial planning, particularly in the context of tropical urban forests such as SACF.

In conclusion, this density map demonstrated the concentration of research activity in three primary areas: 1) geospatial methods for canopy monitoring (NDVI, Sentinel-2, LULC); 2) urban forest ecology and biodiversity conservation; and 3) urban planning integration for forest conservation. This type of visualization is particularly useful for identifying emerging research themes and for guiding future work, such as enhancing the linkage between canopy change detection and species-level biodiversity data in SACF.

Gap analysis for systematic review

Table 3 provides an overview of research on urban forest conversion, changes in canopy cover and the assessment of ecological impacts utilizing geospatial methods. Although extensive research has scrutinized the loss of forests on a global scale and the transformations in land use, serious research shortcomings remain relating to small tropical urban forests such as SACF.

A considerable portion of the existing body of literature emphasizes expansive forested areas or rural conservation regions, with a lesser focus on fragmented urban forests that face immediate development pressures. While often, the loss of canopy cover is evaluated, many studies depended on medium-resolution imagery, such as Landsat, which may fail to capture the fine-scale changes that are important for biodiversity conservation in smaller urban forests. In addition, a palpable incongruity exists between the canopy metrics captured through remote sensing and the biodiversity information sourced *in situ*, causing a limitation in obtaining an insight into how canopy degradation affects habitat quality and species variation.

Even though fragmentation analysis and patch metrics are well-established in landscape ecology, their use in urban forest remnants across Southeast Asia is not adequately represented. Furthermore, a restricted set of studies tied geospatial information to urban policy actions, limiting the opportunities to turn research results into viable conservation approaches. Often, temporal analyses are limited to just two time points, overlooking gradual trends in canopy degradation and seasonal fluctuations that could influence habitat conditions.

Mitigating these shortcomings is important for SACF, given that rapid urbanization creates a pressing challenge

to canopy preservation and biodiversity. Future research should aim to utilize high-resolution Sentinel-2 imagery, integrate species occurrence data (such as iNaturalist), apply fragmentation metrics specifically designed for small urban forests and incorporate geospatial findings into local planning and conservation initiatives. These strategies should improve the capacity to detect, monitor and mitigate the ecological consequences of forest conversion, thereby ensuring the long-term viability of SACF's ecosystem services and biodiversity.

This conceptual framework (see Fig. 5) was developed through the synthesis of current knowledge on urban forest conversion, its drivers and its ecological impacts. Drawing on empirical findings from other studies, the framework integrated spatial analysis, biodiversity indicators and policy considerations to guide the assessment of ecological impacts in community forest.

The framework began with key parameters identified in the literature, including NDVI analysis, canopy cover mapping, LULC classification, fragmentation metrics and bioindicator overlays. These parameters were complemented by insights from related research on urban canopy studies, biodiversity and habitat mapping, green space accessibility, deforestation, landscape fragmentation and ecosystem services valuation.

In addition, the review highlighted common causal factors driving urban forest conversion such as urbanization, infrastructure expansion, agricultural encroachment, policy gaps and habitat degradation. To address these factors, the framework incorporated multi-source datasets such as Sentinel-2 MSI imagery for fine-scale monitoring, SACF boundary shapefiles, iNaturalist butterfly records as ecological bioindicators and OpenStreetMap topography data.

A GIS-based multi-criteria evaluation approach, supported by ArcGIS Pro (Esri Inc., Redlands, CA, USA), QGIS (QGIS Development Team, Open Source Geospatial Foundation) and Google Earth Engine (Google LLC, USA) was applied to integrate these data sources. Using reclassification and weighted overlay analysis, the study generated vulnerability maps that spatially identified areas most at risk.

The outcomes of this framework were an evidence-based assessment of canopy loss, biodiversity decline, habitat fragmentation and reduced ecosystem services. By combining remote sensing, GIS tools and ecological insights drawn from the literature, this framework provided a structured methodology to inform conservation planning and to mitigate the impacts of urban forest conversion.

Table 3 Identified research gaps in assessing the ecological impacts of urban forest conversion using geospatial techniques.

ID	Author & Year	Study area	Methodology	Data used	Key findings	Limitations (gaps)
1	Abdul Samad et al. (2024)	Kuala Lumpur, Malaysia	Geographic information system (GIS)-based evaluation of urban forest ecosystem services. This study involves qualitative and quantitative assessments through interviews and document analysis.	Urban forest inventory data, land cover maps from Kuala Lumpur Forest Eco Park.	Identified contributions of urban forests to air quality, recreational spaces and biodiversity conservation. Evaluated ecosystem services, including air purification, nutrient cycling and recreational opportunities.	No integration of temporal canopy change with biodiversity indicators. Lacks analysis using Sentinel-2 imagery, which could enhance canopy cover monitoring and biodiversity linkages.
2	Azari et al. (2022)	Selangor, Malaysia	Multi-temporal Land Use/Land Cover (LULC) change analysis using decision forest-Markov chain model to simulate future land cover trends.	Multi-year Landsat imagery (1999, 2006, 2017).	Detected rapid urban expansion and forest loss in Selangor between 1999 and 2017. Modelled future scenarios for urban sprawl by 2030, highlighting loss of natural vegetation.	Lacks direct biodiversity assessment and did not account for canopy structure and habitat fragmentation, which are crucial for understanding ecological health.
3	Idris and Saleh (2024)	Shah Alam, Malaysia	Remote sensing & GIS-based LULC prediction to model urban growth patterns and environmental impacts.	Satellite imagery, urban planning layers (such as zoning).	Modeled the future urban growth in Shah Alam, highlighting potential threats to green spaces and ecological health.	No biodiversity integration. Canopy structure was not quantified and the link between land cover change and species diversity was missing.
4	Lim et al. (2024)	Bukit Chera, Shah Alam Community Forest (SACF) corridor, Malaysia	Habitat connectivity & wildlife crossing assessment using field surveys and GIS habitat maps.	Field surveys, GIS habitat maps.	Identified critical wildlife corridors in Shah Alam landscape and assessed their importance for maintaining ecological connectivity.	No canopy time series/ normalized difference vegetation index (NDVI) trends; lacks a clear link between biodiversity and canopy loss in the urban context.
5	Muhammad and Lam (2023)	Peninsular Malaysia	Google Earth Engine classification using random forest (RF) & support vector machine (SVM) for forest mapping.	Landsat & Sentinel imagery.	Developed robust classifiers for forest/non-forest mapping, demonstrating the accuracy of RF and SVM techniques in forest monitoring.	No fragmentation metrics or species occurrence overlay were considered, which are essential for assessing ecological health.
6	Danneck et al. (2023)	Malaysia (urban networks)	Connectivity analysis of green patches using GIS and graph-based metrics (such as corridors, patch networks).	GIS connectivity metrics, land cover maps, expert-based parameterization of urban green patches.	Identified the role of connected green patches in conserving biodiversity in urban landscapes, emphasizing the need for strategic green corridors.	No temporal canopy loss trajectory considered. Lacks use of Sentinel-2 time series data to assess long-term canopy changes and its effects on biodiversity.
7	Azizah et al. (2021)	Malang, Indonesia	Field survey of butterfly diversity, examining species abundance, richness and diversity in urban green spaces.	Butterfly species inventory from urban green spaces.	Butterfly abundance varied significantly by habitat conditions in urban areas. Highlighted the importance of maintaining green spaces for sustaining urban biodiversity.	No integration of GIS/remote sensing canopy change with butterfly diversity. Lacks NDVI or Sentinel-2 data to link canopy health with species occurrence.

Table 3 Continued

ID	Author & Year	Study area	Methodology	Data used	Key findings	Limitations (gaps)
8	Badiye and Gajbe (2023)	Urban India	Urban biodiversity survey focusing on butterfly occurrence and ecological monitoring across green spaces in urban areas.	Butterfly occurrence data, field surveys in urban parks and gardens.	Green spaces in urban areas contribute significantly to butterfly diversity, showing that urbanization does not always diminish biodiversity if green spaces are well-managed.	No spatial linkage to canopy loss or fragmentation. Lacks remote sensing data to assess the relationship between green space fragmentation and biodiversity.
9	Li et al. (2024)	Tropical forests	Tree canopy cover time series fusion using Sentinel-1 synthetic aperture radar and Sentinel-2 (optical) to monitor canopy loss and regrowth in tropical forests.	Sentinel-1 and Sentinel-2 time-series data.	Accurate monitoring of tropical forest change, especially for detecting canopy cover loss and regrowth patterns over time.	Not focused on urban contexts; limited application for small-scale urban forests such as SACF, missing key urban-specific variables like human influence.
10	Nor et al. (2021)	Southeast Asian cities	Urban green space evolution under rapid expansion, using remote sensing and satellite imagery to analyze green space decline.	Satellite imagery, urban growth data.	Documented the decline in green spaces across Southeast Asian cities due to urbanization, highlighting the pressure on urban biodiversity.	No canopy health assessment (NDVI) or biodiversity impacts were considered in the analysis.
11	Illarionova et al. (2021)	Global test sites	Weakly supervised tree species mapping using Sentinel-2 multispectral imagery (MSI) to classify species presence in forested areas.	Sentinel-2 MSI.	Demonstrated the feasibility of species-level mapping using Sentinel-2 imagery, with accurate classification of different tree species essential for understanding the in urban forests.	No ecological impact linkage. The study did not assess fragmentation or biodiversity overlay, which are ecological consequences of land use changes.
12	Durán et al. (2020)	Global	Framework to measure biodiversity impacts of land conversion. Used biodiversity metrics based on species occurrence data.	Species occurrence datasets, LULC datasets.	Developed practical metrics for quantifying biodiversity loss due to land conversion. The framework helps identify biodiversity risks in various land conversion scenarios.	Not specific to urban forests; lacks canopy/fragmentation mapping, which is essential for urban forest biodiversity assessment.
13	Finizio et al. (2024)	Global	Systematic review & meta-analysis on remote sensing applications for urban biodiversity. Evaluates the use of remote sensing technologies such as satellite imagery and unmanned aerial vehicles (UAVs).	Various satellite datasets (including Sentinel), light detection and ranging and UAVs.	Found that high-resolution remote sensing advances biodiversity monitoring in cities, but its application in tropical urban forests remains limited.	Limited cases in tropical urban forests and no integration with citizen-science biodiversity data.
14	Sharma et al. (2025)	Global	Remote sensing + iTree Eco synthesis to evaluate urban forests' contribution to ecosystem services.	Satellite imagery, urban forest inventory.	Integrated urban forest structure with ecosystem service valuation, offering a comprehensive assessment tool for urban planners.	Limited application in tropical Southeast Asia; no case study offering a comprehensive assessment specific to urban forests like SACF.
15	Zhao et al. (2022)	Global (bibliometric analysis of Scopus publications)	Bibliometric review of urban biodiversity research using Scopus and Web of Science (WoS) data.	Scopus/WoS bibliographical data.	Mapped global research hotspots and themes in urban biodiversity, highlighting trends in research focus.	No empirical canopy analysis. Limited guidance on integrating Sentinel-2/NDVI workflows for biodiversity monitoring.

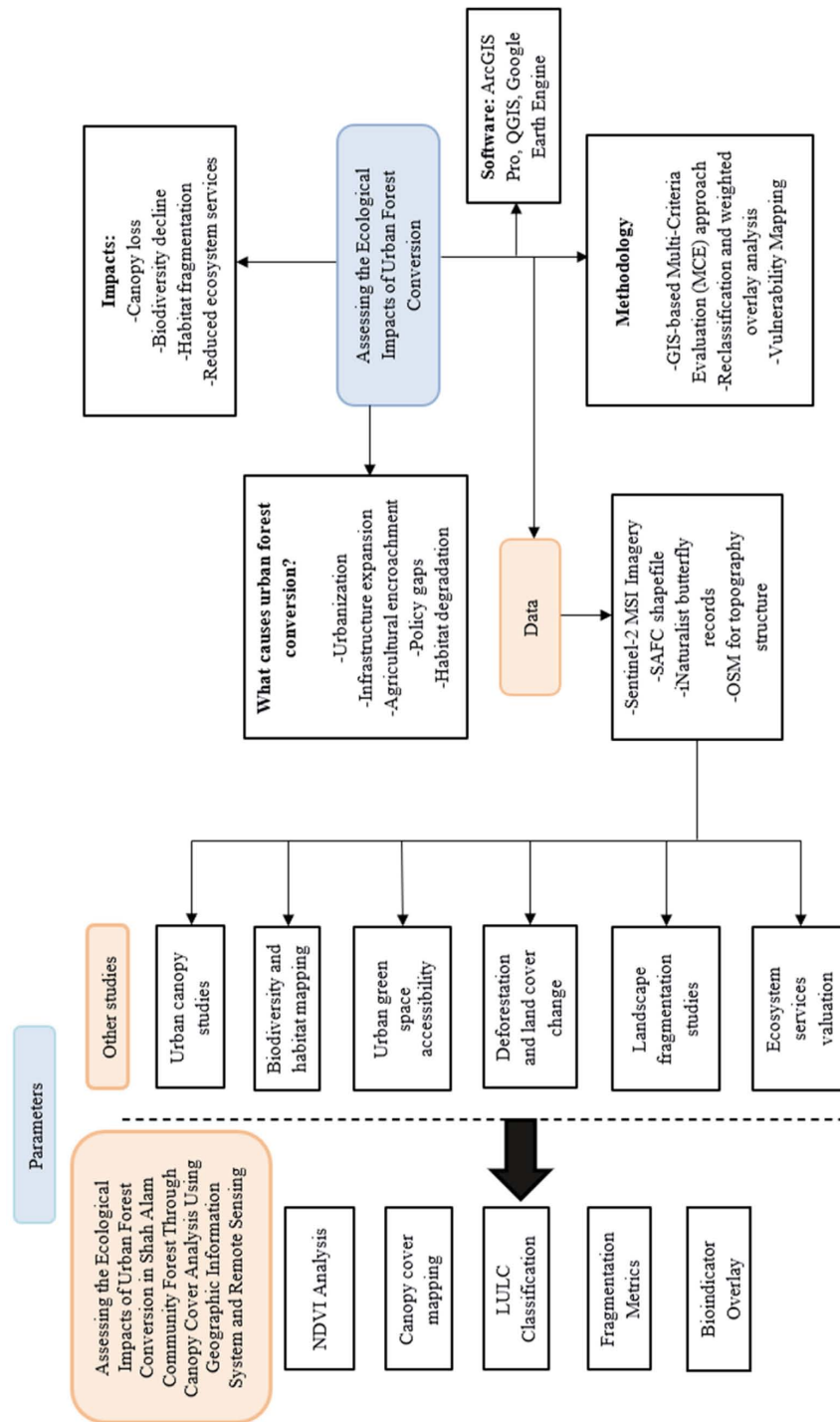


Fig. 5 Conceptual framework for assessing ecological impact of urban forest conversion that integrates spatial analysis, biodiversity indicators and policy considerations, where NDVI = normalized difference vegetation index, LULC = Land Use and Land Cover, MSI = Multispectral Imager, SACF = Shah Alam Community Forest, OSM = Open Street Map, GIS = Geographical Information System.

Discussion

This systematic review investigated the ecological impacts

of urban forest conversion, with a particular focus on SACF, by interrogating literature on canopy cover change, biodiversity loss and habitat fragmentation using geospatial techniques (Li et al., 2022; Rasli and Kanniah, 2023). The findings

revealed that urban forest conversion in rapidly developing regions, particularly in tropical areas, poses major threats to ecosystem stability, biodiversity persistence and the delivery of ecosystem services (Nor et al., 2021; Rahim et al., 2024). As shown in other studies, forest loss in peri-urban landscapes leads to canopy cover reduction, increased fragmentation and degradation of critical habitats for species, such as butterflies and other pollinators (Azizah et al., 2021; Wang et al., 2025), directly influencing ecological resilience and long-term sustainability (Durán et al., 2020).

The current review highlighted that while geospatial methods, such as GIS-based change detection, NDVI analysis and landscape fragmentation metrics, are widely applied in forest monitoring (Shahtahmassebi et al., 2021; Sharma et al., 2025), few studies have integrated these techniques with species occurrence data to evaluate biodiversity impacts at a fine spatial scale (Badiye and Gajbe, 2023; Trivedi et al., 2024). In particular, this is evident in tropical urban forests, where high biodiversity coexists with intense development pressures (Danneck et al., 2023). The combination of Sentinel-2 imagery, supervised land cover classification and spatial overlay with biodiversity occurrence data offers a promising approach; however, this combination remains underutilized in the context of small-scale but ecologically critical forest patches such as SACF (Idris and Saleh, 2024; Li et al., 2024).

Furthermore, the synthesis of literature revealed an upward

trend in research on urban forest change detection and ecological assessment between 2020 and 2024, reflecting growing awareness of the importance of urban green infrastructure in climate adaptation, carbon sequestration and biodiversity conservation (Baró et al., 2014; Rahim et al., 2024). Despite this progress, major research gaps persist: 1) a lack of long-term temporal analyses to track progressive canopy loss in the same location (Kanniah et al., 2021); 2) minimal integration between canopy cover change metrics and in-situ biodiversity data (Azizah et al., 2021; Wang et al., 2025); and 3) insufficient application of fragmentation analysis tailored to urban forest patches within tropical megadiverse regions (Danneck et al., 2023; Lim et al., 2024). The key milestones are shown in Fig. 6.

Fig. 6 provides a timeline of the research milestones in ecological assessment of urban forest, indicating the evolution from early conceptual and bibliometric approaches to the use of canopy cover analysis using satellite imagery, biodiversity studies and landscape connectivity measurements. Up-to-date achievements leave a trail of datasets based on the combination of Sentinel-2 scenes with NDVI through canopy time series and ecosystem services assessments, increasingly incorporating data-driven, integrative geospatial methods. This development shows urban forest research taking the step from descriptive evaluation toward sophisticated, multi-dimensional ecological studies.

The current review has emphasized the need for future

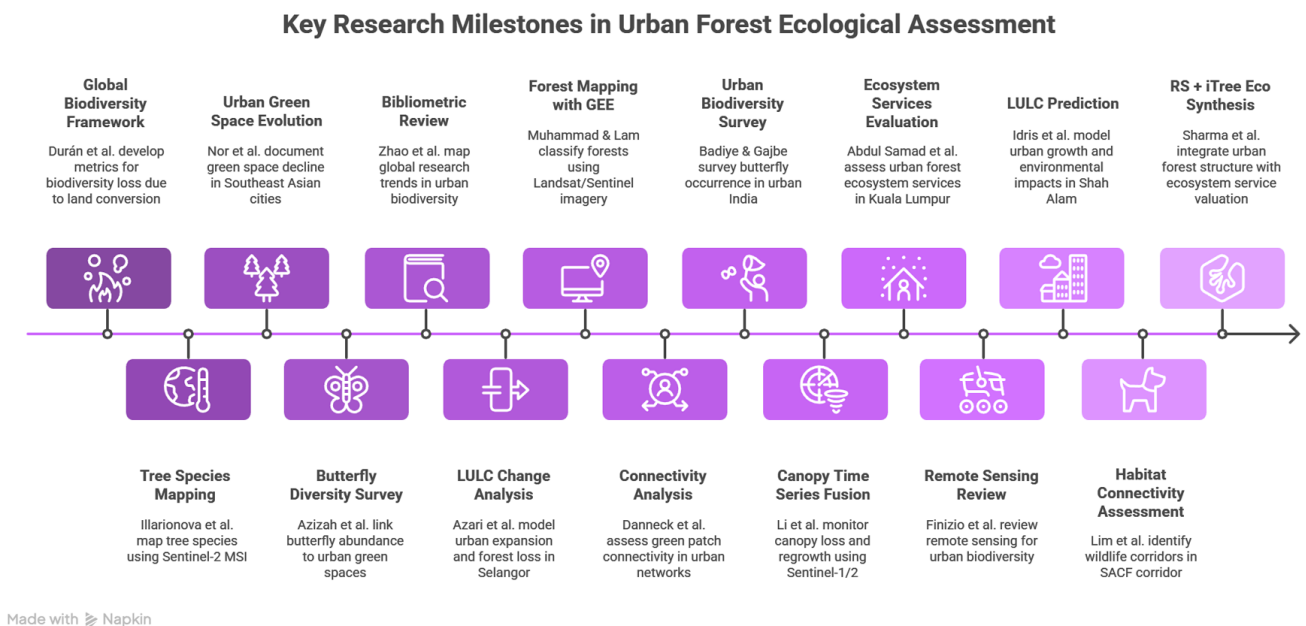


Fig. 6 Determined key research milestones in urban forest ecological assessment, where GEE = Google Earth Engine, LULC = Land Use and Land Cover, RS = Remote Sensing, MSI = Multispectral Imager, SACF = Shah Alam Community Forest.

research to bridge these gaps by adopting multi-temporal, multi-source remote sensing approaches combined with ecological field data (Finizio et al., 2024; Li et al., 2024). Advancements in high-resolution satellite imagery, object-based image analysis and cloud-based geospatial platforms, such as Google Earth Engine, will enable more precise monitoring of forest conversion patterns (Muhammad and Lam, 2023). Furthermore, integrating ecological indicators into geospatial analyses will improve understanding of the links between habitat quality, biodiversity trends and forest spatial configuration (Durán et al., 2020; Sundara Rajoo et al., 2021). Therefore, this introduced a set of integrative solutions that are justified by the research gaps shown in Fig. 7, namely, enhancing temporal monitoring through Sentinel-2 time-series data, coupling canopy metrics with *in situ* biodiversity observations (such as butterfly records), applying fragmentation indices tailored to small tropical forests and embedding geospatial evidence into urban policy and planning frameworks.

The recognized research voids were classified into three main clusters. The first involved gaps in GIS techniques, including the spatial linkage between canopy loss and fragmentation metrics and ecological health assessments. The second emphasized Sentinel-2 application gaps, primarily in terms of poor integration of multi-temporal canopy change analysis and under-explored of Sentinel-2 time-series imagery in tropical urban forests. The third cluster considered

methodological limitations such as no direct assessment of biodiversity, little or no inclusion of species occurrence data and poor consideration for urban-specific climate variables driving forest conversion. These three categorizations and their implications for urban forest research are summarized in Fig. 6.

Ultimately, strengthening such integrative approaches will support evidence-based policy formulation, conservation prioritization and long-term monitoring strategies to safeguard the ecological integrity of SACF and similar urban forest ecosystems in the tropics (Nor et al., 2021; Urbanice Malaysia, 2022). Hence, this paper has summarized how leveraging geospatial technology will be able to deliver a holistic framework for canopy monitoring, biodiversity integration, fragmentation assessment and policy incorporation, as outlined in Fig. 8. Urban forests provide critical ecological, climatic and social benefits, yet they are often overlooked in conservation science. Historically, research on these forests has been limited in scope, with insufficient attention to their unique challenges such as small patch sizes, high fragmentation and rapid land-use change. Fig. 8 illustrates a framework for addressing these shortcomings by improving research methods and linking scientific findings directly to conservation outcomes.

This framework outlines a pathway to improve research methods and to translate findings into effective conservation outcomes. It lays out interconnected strategies (high-resolution imagery, species data integration, fragmentation metrics, policy incorporation) that together improve research methods

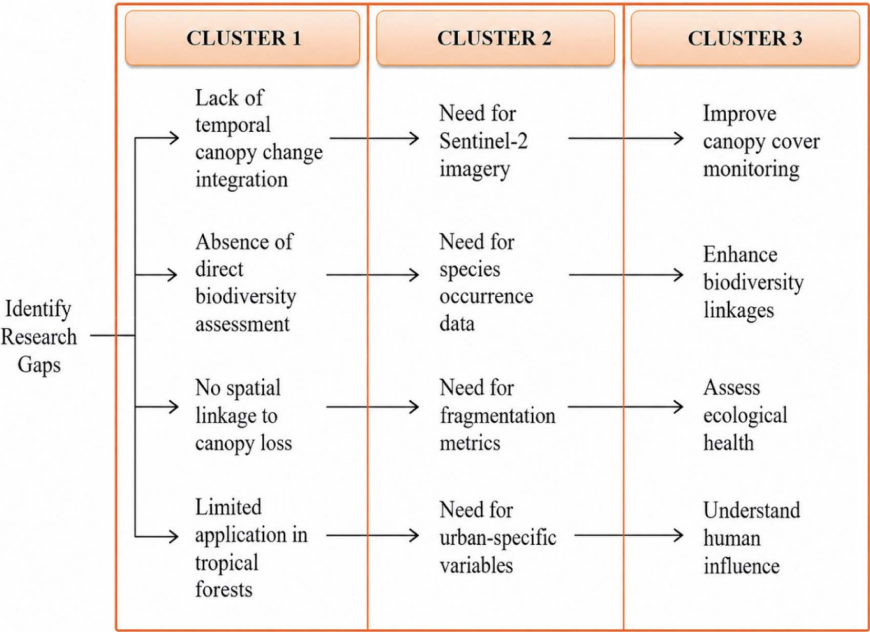


Fig. 7 Identified clusters of research gaps in urban forest conversion.

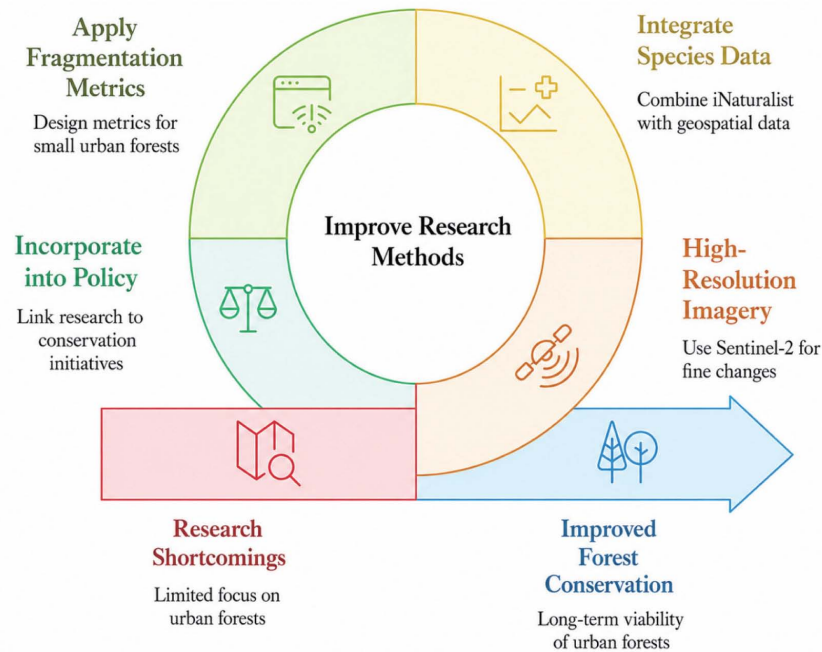


Fig. 8 Framework for preserving urban forest with geospatial methods by improving research methods.

and conservation outcomes for urban forests.

Leveraging high-resolution remote sensing

Advances in satellite imagery, particularly from systems such as Sentinel-2, enable detection of fine-scale canopy changes, vegetation health trends and habitat loss in near real time. These tools allow researchers to monitor urban forest dynamics with unprecedented spatial and temporal precision, facilitating early detection of threats and more effective management interventions.

Integrating species occurrence data with geospatial information

Citizen science platforms, such as iNaturalist, provide rich, spatially explicit biodiversity records contributed by the public. When combined with geospatial datasets, such as land-cover maps, topography and urban infrastructure data, these observations can reveal how species distributions align with environmental variables, habitat patches and urban pressures. This integrated approach supports both ecological research and community engagement.

Applying fragmentation metrics tailored to urban forests

Often, traditional forest metrics fail to capture the fine-

scale structure of small, isolated patches typical of urban landscapes. Researchers can assess habitat quality, ecological connectivity and edge effects with greater accuracy by designing fragmentation indices specific to these contexts. Such metrics are essential for understanding how urban development influences species persistence and ecological function.

Incorporating research into policy and planning

Scientific insights must be translated into actionable policy to ensure long-term conservation success. Linking ecological findings to urban planning processes, green infrastructure projects and biodiversity strategies ensures that research informs land-use decisions. Embedding this knowledge in local governance also increases accountability and resource allocation for protecting urban forests.

Together, these four strategies form an iterative cycle in which improved research methods generate more accurate, relevant data. This, in turn, guides conservation planning, which feeds back into further research priorities. By adopting this framework, researchers and policymakers can ensure the long-term viability of urban forests and the ecosystem services they provide.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

The Shah Alam Community Forest Society provided site information and Universiti Teknologi MARA gave access to databases and software tools. Appreciation is extended to colleagues for feedback during manuscript preparation.

References

- Abdul Samad, I.A., Baharuddin, Z.M., Md Jani, H.H. 2024. Evaluation of ecosystem services contributions on urban forests in Kuala Lumpur. *J. Archit. Plann. Constr. Manage.* 14: 1. doi.org/10.31436/japcm.v14i1.697
- Azari, M., Billa, L., Chan, A. 2022. Multi-temporal analysis of past and future land cover change in the highly urbanized state of Selangor, Malaysia. *Ecol. Process.* 11: 2. doi.org/10.1186/s13717-021-00350-0
- Azizah, A., Mustafa, I., Gama, Z.P., Leksono, A.S. 2021. The diversity and abundance of butterfly [Lepidoptera] in several urban green spaces of Malang city. *IOP Conf. Ser. Earth Environ. Sci.* 741: 012057. doi.org/10.1088/1755-1315/741/1/012057
- Badiye, V.H., Gajbe, P.U. 2023. Butterfly diversity in an urban area illustrates the significance of green spaces in urban biodiversity conservation. *Arthropods* 12: 111–119.
- Baró, F., Chaparro, L., Gómez-Baggethun, E., Langemeyer, J., Nowak, D.J., Terradas, J. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: The case of urban forests in Barcelona, Spain. *Ambio.* 43: 466–479. doi.org/10.1007/s13280-014-0507-x
- Chowdhury, S., Dubey, V.K., Choudhury, S., et al. 2023. Insects as bioindicator: A hidden gem for environmental monitoring. *Front. Environ. Sci.* 11: 1146052 doi.org/10.3389/fenvs.2023.1146052
- Danneck, J., Chin Fung Tiang, D., Ngo Duc, K., Azhar, B., Sanusi, R., Campos-Arceiz, A., Lechner, A.M. 2023. Conserving urban tropical biodiversity by connecting networks of green patches. *Integr. Conserv.* 2: 80–94. doi.org/10.1002/inc3.21
- Durán, A.P., Green, J.M.H., West, C.D., Visconti, P., Burgess, N.D., Virah-Sawmy, M., Balmford, A. 2020. A practical approach to measuring the biodiversity impacts of land conversion. *Methods Ecol. Evol.* 11: 910–921. doi.org/10.1111/2041-210X.13427
- Finizio, M., Pontieri, F., Bottaro, C., Di Febraro, M., Innangi, M., Sona, G., Carranza, M.L. 2024. Remote sensing for urban biodiversity: A review and meta-analysis. *Remote Sens.* 16: 4483. doi.org/10.3390/rs16234483
- Idris, R., Saleh, M.T.M. 2024. Remote Sensing and GIS-Based LULC Prediction in Shah Alam: A Strategy for Sustainable Urban Growth and Development. *BioEnv.* 2: 85–96. doi.org/10.24191/bioenv.v2i3.71
- Illarionova, S., Trekin, A., Ignatiev, V., Oseledets, I. 2021. Tree species mapping on Sentinel-2 satellite imagery with weakly supervised classification and object-wise sampling. *Forests* 12: 1413. doi.org/10.3390/f12101413
- Kanniah, K.D., Kang, C.S., Sharma, S., Aldrie Amir, A. 2021. Remote sensing to study mangrove fragmentation and its impacts on leaf area index and gross primary productivity in the south of Peninsular Malaysia. *Remote Sens.* 13: 1427. doi.org/10.3390/rs13081427
- Li, G., Fang, C., Li, Y., et al. 2022. Global impacts of future urban expansion on terrestrial vertebrate diversity. *Nat. Commun.* 13: 1628. doi.org/10.1038/s41467-022-29324-2
- Li, Z., Ota, T., Mizoue, N. 2024. Monitoring tropical forest change using tree canopy cover time series obtained from Sentinel-1 and Sentinel-2 data. *Int. J. Digit. Earth.* 17: 2312222. doi.org/10.1080/17538947.2024.2312222
- Lim, T., Teoh, A., Hii, A., Dayana, A. 2024. Habitat connectivity and wildlife crossings in Bukit Cherakah Forest Corridor, Shah Alam, Selangor. *Malayan Nat. J.* 76: 445–458. doi.org/10.62613/mnj.24764.04
- Lin, Y., Huang, S., Fang, W., Fan, S., Ran, C., Dang, E., Fu, W., Zhu, Z. 2025. Progress and evolution of hotspots in butterfly diversity research in green spaces. *Environ. Sci. Pollut. Res.* 32: 3147–3159. doi.org/10.1007/s11356-024-32269-2
- Muhammad, F.N., Lam, K.C. 2023. Forest mapping in Peninsular Malaysia using Random Forest and Support Vector Machine Classifiers on Google Earth Engine. *Malaysian J. Soc. Space.* 19: 1–16. doi.org/10.17576/geo-2023-1903-01
- Nor, A.N.M., Aziz, H.A., Nawawi, S.A., et al. 2021. Evolution of green space under rapid urban expansion in Southeast Asian cities. *Sustainability* 13: 12024. doi.org/10.3390/su132112024
- Porath, I.A.T., Aranda, R. 2020. Frugivorous butterflies (Lepidoptera: Nymphalidae) as a habitat quality indicator in Cerrado urban fragment. *EntomoBrasilis.* 13: e904. doi.org/10.12741/ebrazilis.v13.e904
- Rahim, N.H., Razak, S.A., Chang, X., et al. 2024. Ecosystem Services by Urban Forest (UF) towards Climate Change Adaptation: A Review. *Pol. J. Environ. Stud.* 33: 3503–3513. doi.org/10.15244/pjoes/177147
- Rasli, F.N., Kanniah, K.D. 2023. Kuala Lumpur green space fragmentation index analysis and green corridors suggestion using Geographic Information System. *J. Adv. Geospat. Sci. Technol.* 3: 176–200. doi.org/10.11113/jagst.v3n2.66
- Shah Alam Community Forest Society. 2020. About Us –Shah Alam Community Forest Society. <https://shahalamforest.org/wp/about/>, 7 August 2024.
- Shahtahmassebi, A.R., Li, C., Fan, Y., et al. 2021. Remote sensing of urban green spaces: A review. *Urban For. Urban Green.* 57: 126946. doi.org/10.1016/j.ufug.2020.126946
- Sharma, G., Morgenroth, J., Richards, D.R., Ye, N. 2025. Advancing urban forest and ecosystem service assessment through the integration of remote sensing and i-Tree Eco: A systematic review. *Urban For. Urban Green.* 104: 128659. doi.org/10.1016/j.ufug.2024.128659
- Sundara Rajoo, K., Karam, D. S., Abdu, A., Rosli, Z., James Gerusu, G. 2021. Urban forest research in malaysia: A systematic review. *Forests* 12: 903. doi.org/10.3390/f12070903
- Sushmita, Sharma, B., Sharma, D.S., Kumar, A. 2022. Butterflies of

- Urban Landscape: A Review on Conservation Ecology of Diurnal Lepidoptera. *Ela Journal of Forestry and Wildlife* 11: 1262–1272
- Trivedi, G., Vishwakarma, H., Sharma, V.K. 2024. Spatial Patterns of Butterfly and Host Plant Diversity Across Urban, Wetland and Peripheral Habitats of Indore, Central India. *Natl. J. Life. Sci.* 21: 15–27.
- Urbanice Malaysia. 2022. Shah Alam Community Forest (SACF) Ecosystem Services Report 2022.
- Van Eck, N.J., Waltman, L. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* 84: 523–538. doi.org/10.1007/s11192-009-0146-3
- Wang, K., Qi, Y., Hu, Y., Han, D. 2025. Distribution and influences on butterfly diversity in urban park green spaces: A case study of Harbin, China. *Ecol. Evol.* 15: e71554. doi.org/10.1002/ece3.71554
- Zhao, X., Li, F., Yan, Y., Zhang, Q. 2022. Biodiversity in Urban Green Space: A Bibliometric Review on the Current Research Field and Its Prospects. *Int. J. Environ. Res. Public Health*.19: 12544. doi.org/10.3390/ijerph191912544