18(1s), Spring 2026

Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: http://www.aejournal.ir

Original Research Paper

Climate-Adaptive Urban Landscapes for Supporting Wildlife Populations Under Global Warming Scenarios

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Abstract: Habitat fragmentation, biodiversity loss and the urban heat island effect are all driven by rapid urbanization and global warming and are major threats to wildlife populations. This study suggests a framework for the implementation of a climate adapted city landscape by combining Green Infrastructure, ecological corridors, climate resilient vegetation, NbS, GIS, AI and IoT based monitoring of the environment to enhance ecological resilience of urban areas. Sentinel-2 MultiSpectral Instrument (MSI) data was used for the implementation of the framework for land-use and vegetation mapping, while Landsat-9 Operational Land Imager/Thermal InfraRed Sensor (OLI/TIRS) data was used for land surface temperature and urban heat island assessment. Spatial analysis with the help of artificial intelligence was used to assess the suitability of the habitats and to improve the ecological connectivity in the future climatic scenarios. Habitat connectivity, normalized difference vegetation index (NDVI), habitat suitability index, species richness, land surface temperature (LST), carbon sequestration potential and ecosystem resilience were used for performance analysis. Throughout the implementation, the habitat connectivity increased from 0.58 to 0.71, the mean NDVI from 0.43 to 0.56, the habitat suitability index from 0.61 to 0.76, the number of species in urban habitat increased by 18.4%, the mean land surface temperature decreased by 2.7°C, the estimated carbon sequestration increased by 16.9%, and the overall ecosystem resilience index increased by 0.81 to 0.64. The results show that the use of Sentinel-2 MSI and Landsat-9 observations in conjunction with AI-driven planning has a significant impact on the protection of urban biodiversity, climate action and bolstering the creation and management of resilient, wildlife-friendly cities in a future climate.

Keywords: Urban biodiversity conservation; Climate-adaptive landscape planning; Ecological corridor connectivity; Remote sensing (Sentinel-2/Landsat-9); AI-assisted habitat suitability modeling; Urban heat island mitigation, Climate Action

I. Introduction

The accelerating global warming, coupled with unprecedented urban growth, is changing the nature and dynamics of urban ecosystems globally by displacing forests, wetlands and grasslands with impervious infrastructure, with limited space for wildlife [1]. Urban and peri-urban landscapes that were previously buffers between nature and urbanization are now being increasingly exposed to the impacts of intensifying heatwaves, irregular rainfall and compounding socio-ecological stresses on landscape capacity to support nature [2]. Although climate change adaptation is now part of

***Corresponding Author:**
Received: 24th April, 2026; Revised: 11th May, 2026; Accepted: 24th May, 2026; Available Online: 6th June, 2026
(DOI): 10.70102/AEJ.2026.18.1s.68

the urban policy agenda, the translation of climate change assessment into spatial adaptation solutions that are sensitive to biodiversity is not consistent across regions and institutional settings [3]. As both the surface and air temperature increase, and built-up cover expands, the thermal and hydrological niche of urban fauna is shrinking and becoming more fragmented, leaving species with few options except to live in the remaining green areas which are also becoming more isolated and small as urban development continues [4]. Historically, urban green spaces provided refuge for species including pollinators, birds and small mammals, but are increasingly facing the challenge of scaling back from urban development and the rapidly changing climate, impacting their future ability to support viable populations of wildlife [5]. Traditional urban planning, which is mostly focused on infrastructure efficiency, land use zoning, and economic development, rarely considers ecological connectivity, climatic projections, and habitat suitability as a design criterion, and leaves the landscape structurally green, but functionally green-poor for wildlife connectivity [6]. Where street-level greening and the consideration of ecological regeneration are being adopted, they are often done as short-term, cosmetic and/or stormwater management solutions, not as elements of a larger ecological network with the goal of addressing climate change [7]. The gaps identified highlight the need for a comprehensive, data-informed, and climate-smart approach to landscape planning in cities that combines remote sensing, ecological modeling, and artificial intelligence to inform urban design that will be resilient to climate change and promote biodiversity. Inspired by this need, the present study proposes and tests an integrated urban landscape framework that integrates observations from Sentinel-2 MSI and Landsat-9 OLI/TIRS satellite data with GIS-based spatial analysis and AI-driven decision support tools for optimizing the placement of green infrastructure, the creation of ecological corridors, and the suitability of vegetation under projected warming scenarios, and quantifies the improvements in vegetation health, thermal comfort, carbon sequestration, and overall ecosystem resilience derived from the implementation of the framework.

The following are a brief summary of the key contributions of this research:

- Suggests a unified GIS-AI system that combines Sentinel-2 and Landsat-9 data to inform wildlife habitat planning for an urban area with changing climate.
- Measures tangible benefits of the framework in terms of habitat connectivity, NDVI, species richness and surface temperature.
- Demonstrates a repeatable methodology that is monitored through the IoT cloud, that is optimized for AI, and that creates resilient urban landscape that is wildlife-friendly.

II. Climate Change Impacts on Urban Wildlife

Increasing habitat degradation, changes in microclimates, and disruption of ecological connectivity for species to forage, disperse and reproduce are exacerbating pressures on urban wildlife due to global warming. Fragmented green patches had higher surface temperatures, lower moisture levels, lower vegetation vigor and in total made habitat less suitable for both sedentary and migratory species. Many species that thrive in urban environments and are moving towards higher latitudes and elevations also have limited options for movement because of the fragmented and thermally inhospitable landscapes. These interacting stressors need to be understood to design resilient, climate adaptive urban ecosystems to support biodiversity under future warming trajectories.

A. Habitat Fragmentation and Biodiversity Loss

The relentless processes of urban growth invariably break up continuous natural habitats into discrete patches, thereby interrupting the ecological processes wildlife need to feed, breed and migrate. The less green space that remains, the smaller the effective size of the population, and the higher the risk of local extinction of sensitive taxa as impervious surfaces replace forests, grasslands and wetlands and remaining green spaces become smaller and more isolated. The phenology, growth rates and species composition of plant communities within these fragments are also facing stress as changing climate conditions (higher temperatures, different precipitation regimes, and CO_2 concentrations) are impacting them, with cascading impacts to the fauna that rely on these plant communities for food and shelter [8]. Legacy landscapes, with higher structural heterogeneity and historic vegetation, represent some examples of how the continuity and ecological value of corridors can be maintained even in the face of strong development pressures when conservation is explicitly programmed into a planning process, as opposed to tackling it as a post-development conservation concern [9]. In fragmented urban habitats, biodiversity declines over time unless interventions are made to stop it, as edge effects, more human activity and microclimatic extremes progressively reduce the quality of the habitat that remains. To turn this around requires landscape scale measures to restore structural connectivity, conserve legacy plant communities and to explicitly consider the compounding effects of climate change on fragmented ecological networks that extend across the urban landscape.

B. Urban Heat Island Effects on Wildlife Habitats

In urban areas, the urban heat island (UHI) effect is caused by the high amount of impervious cover, low vegetation cover, and anthropogenic heat output, which increase the land surface and air temperature much higher than neighboring rural areas, and results in thermally unfriendly conditions for wildlife on the basis of temperature sensitivity. High-resolution satellite imagery can be used to automatically determine the extent and intensity of the UHI, showing that the temperature of dense urban cores can be several degrees higher than that of green spaces in the periphery, which can have a direct impact on the thermal tolerance, water requirements and activity of species [10]. The spatial accuracy of heat-stressed areas and cooler vegetated refuges identified using a deep learning-based segmentation technique and vision-transformer methods, applied to remote sensing and sensor-network data, further enhanced the accuracy of spatial mapping for targeted cooling interventions [11]. Chronic exposure to higher surface temperatures leads to increased metabolic stress, poor reproductive success and behavioral changes for urban-adapted birds, insects and small mammals, such as migrating to cooler microhabitats and being more active at night. Green corridors, shaded canopy networks and water elements act as buffers to these impacts, but protection benefits vary based on their strategic location in relation to heat island cores. For urban landscapes to provide sustainable habitats in a future warmer climate, UHI mapping and mitigation of UHI intensity are therefore prerequisites.

C. Species Distribution Shifts under Climate Change

With climate change affecting regional climates, the environmental envelopes of many species' habitats are shifting in space, leading to a need for urban wildlife to shift habitats across space as well in order to persist at a local level. Systematic reviews of NbS deployments in a variety of urban environments show that closely spaced green infrastructure can help mitigate some of these changes by creating transitional habitat corridors that enable species to move over time, rather than have to deal with sudden range reductions, but there are cautions that benefits are not necessarily even and that NbS can have unintended consequences when poorly placed [12]. At the building scale and district scale, other adaptation strategies such as green roofs, permeable surfaces and increased canopy cover have additional impacts on the local microclimate that affect the ability of species to persist or not, depending on the extent to which these strategies are connected to the broader landscape [13]. Some species are especially susceptible to loss in climate envelopes: those with low thermal tolerances and low dispersal are particularly vulnerable because isolated urban green patches may not be able to keep up with their changing climatic needs. Planning ahead for these distributional changes should be done through thinking about not just the current suitability of habitats as refuges and corridors, but also the future climate scenarios that will likely occur over the next few decades.

D. Ecological Connectivity and Landscape Resilience

The connectivity of a landscape is an important factor in long-term biodiversity resilience in cities in the face of climate change, defined as the extent to which it allows species to move from habitat patch to patch. In the same way that gradient boosting and graph neural network methods have been used to forecast the demand and optimize routing of complex infrastructure networks [14], similar predictive frameworks can be developed using a combination of graph-based network analysis and machine learning for optimization for systematic, data-driven prioritization of corridors with efficient low-resistance alignments, limiting corridor fragmentation while maximizing connectivity gains. This computational view is complemented by scenario-planning studies in which the potential of NbS has been explored using a variety of future climate scenarios for arid and semi-arid urban environments, and where multiple iterations of green infrastructure designs have been tested to ensure effectiveness before implementation, lowering risk of investing in corridors that ultimately fail to meet ecological goals [15]. Design and policy guidance at a landscape scale has begun to consider that de-polarized, integrated approaches that balance ecological, social and economic priorities will result in more sustainable connectivity outcomes than conservation-only plans at a more narrow scale [16]. In addition to these, systematic evaluations of NbS reveal ongoing implementation barriers, such as coordination across jurisdiction, maintenance and funding, which need to be overcome to ensure NbS can deliver connectivity benefits over time. Together, these approaches suggest that connectivity must be viewed as a specific, measurable design goal, and must be actively managed and monitored, not simply expected to be a side benefit of overall greening measures, for resilient urban landscapes.

III. Climate-Adaptive Urban Landscape Framework

The suggested urban landscape framework for adaptive climate change is a multi-sensor Earth observation platform that will bring together spatial analysis using GIS, artificial intelligence and monitoring systems such as IoT (Internet of Things) technologies into an integrated decision support pipeline for wildlife-sensitive urban planning. The framework's approach integrates vegetation mapping, thermal assessment, and habitat design into a single, iterative process which continually evolves vegetation responses in the landscape as new data from satellite and sensor platforms emerge. This closed-loop approach provides planners with the opportunity to transform raw imagery into actionable, climate-resilient design recommendations and makes explicit the warming scenarios they are considering. Figure 1 shows the overall architecture, where each of the seven main stages of the framework has been marked off sequentially and also as a feedback loop from one to the next.

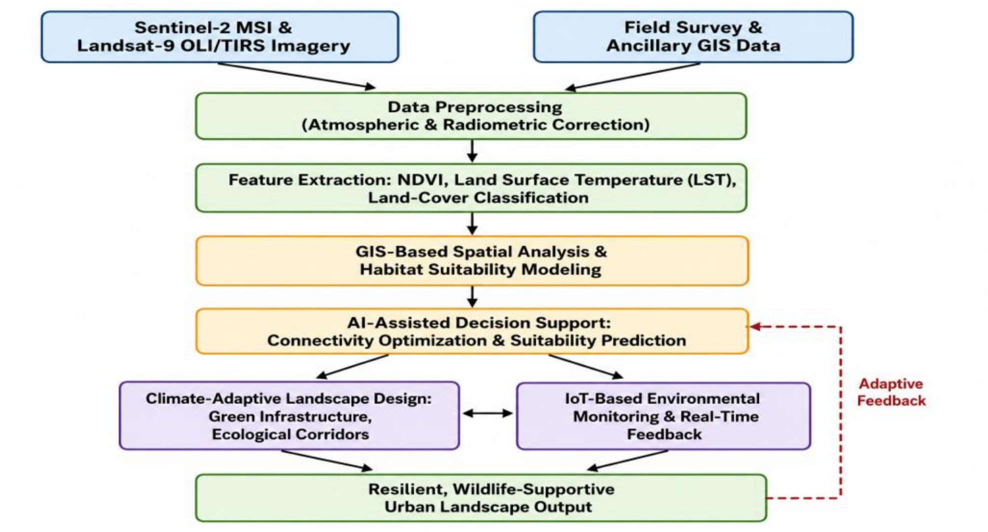

Figure 1. Block diagram of the proposed climate-adaptive urban landscape framework.

The stage-wise flow of the framework is shown in Figure 1, starting with stages of data acquisition and preprocessing using the Sentinel-2 and Landsat-9 datasets, followed by the extraction of features, habitat suitability modeling using GIS, and connectivity optimization using AI. Both green infrastructure design and the monitoring by IoT work simultaneously with each other and share information with each other. A dashed feedback loop connects monitoring outcomes back to the AI decision-support stage, allowing the landscape interventions to be continually adapted with time.

A. Framework Architecture and Implementation Workflow

There are seven interdependent stages of the framework architecture. In the first phase, from the satellite imagery, multispectral and thermal data from Sentinel-2 MSI and Landsat-9 OLI/TIRS are collected for the study area, while using field surveys and ancillary GIS layers. The second stage will correct the spectra and thermal data for consistency with the atmosphere and between acquisition dates. The third stage involves generation of key biophysical indicators such as Normalized Difference Vegetation Index (NDVI) representing vegetation health, land surface temperature (LST) representing thermal condition, and land-cover classes representing spatial land-use pattern, which collectively describe vegetation health, thermal condition and spatial land-use pattern. In the fourth phase, the GIS based spatial analysis integrates these indicators with other information such as topographic and infrastructural data to produce habitat suitability surfaces using weighted overlay modeling. The fifth stage applies AI-based decision support to identify the best location and design of GIFs and ecological corridors based on the suitability surfaces and connectivity metrics under projected climate scenarios. In the sixth stage, these optimized designs are implemented in real landscape interventions, such as the creation of green infrastructure and ecological corridor networks, and at the same time, IoT based sensor solutions are installed that are used for real-time monitoring of the microclimate, soil moisture and vegetation condition. This seventh and final stage combines these outputs to create a resilient and wildlife friendly urban landscape, while monitoring data is continually fed back into the AI decision support stage to inform future action. The staged architecture is designed to be responsive to immediate implementation outcomes and is also feedbacked to the longer-term climate trends.

B. Green Infrastructure and Climate-Resilient Vegetation Planning

Green infrastructure planning is done within the framework, with a focus on drought tolerance, thermal buffering capacity and habitat value species that are climate resilient for specific wildlife groups. Projected temperature and precipitation projections are used to screen candidate plant communities, prioritizing species that are native and climate adaptable, and that are able to provide food and canopy cover in a warming climate. The planning outputs are grouped by type of green infrastructure with target coverage shares, dominant vegetation strategy and expected ecological function as shown in Table 1.

Infrastructure Type	Target Coverage (%)	Vegetation Strategy	Primary Ecological Function
Urban Forest Patches	15	Native, drought-tolerant canopy species	Core habitat & carbon storage
Green Corridors	22	Mixed native shrub-tree strips	Connectivity & species movement
Urban Parks / Pocket Greens	18	Climate-resilient flowering/fruiting species	Pollinator & bird habitat
Riparian Buffers	12	Native wetland & riparian vegetation	Water regulation & refugia
Green Roofs / Walls	10	Sedum & drought-tolerant groundcover	Microclimate cooling

Table 1. Recommended Ecological Infrastructure Types and Vegetation Strategies for Biodiversity-Positive Urban Development

As seen in Table 1, the green corridors have the highest percentage of the total area that is targeted, highlighting their importance as a link to new habitats and ecological flows, whereas the riparian buffers and green roofs provide complementary cooling and water-regulation benefits, and can be integrated into a multifunctional vegetation network that is prioritised to enhance climate resilience and support wildlife.

C. Ecological Corridor Design and Habitat Connectivity Optimization

The ecological corridor design within the framework is formulated as a least cost path optimization problem, where different corridor alignments are compared to a resistance surface synthesized based on the land cover type, the land surface temperature, the slope and the distance to existing green patches. The source and target nodes for the habitat patches identified through land-cover classification and NDVI analysis are connected to each other by the corridors identified by the AI-assisted optimization module, which determines the corridors to minimise cumulative resistance and maximise the structural and functional connectivity between patches. Alignments will be prioritized by creating corridors that connect forest patches, vegetation corridors and urban parks identified in the land-cover classification map, and will avoid creating corridors that duplicate existing ecological links. A series of corridors is then developed and iteratively improved by adding wildlife refuge zones (identified via the land surface temperature analysis), thus enhancing the provision of thermally cool vegetated corridors above routes traversing the urban heat island core. The connectivity optimized design has the potential to improve the likelihood of successful movement of species between habitat patches, and minimizing exposure to thermally stressful urban environments.

D. AI-Assisted Decision Support for Adaptive Landscape Planning

The AI-driven decision support element is at the heart of the framework, converting multiple spatial data sources into actionable landscape recommendations. The scores from the various habitat suitability, connectivity and thermal stress surfaces are merged in a machine learning framework that ranks candidate intervention sites based on their potential to contribute to biodiversity outcomes under future climate scenarios. The module tests combinations of placement of green infrastructure and alignment of the corridors in an iterative manner, and simulates the movement of species and the occupancy of habitats to determine the ecological value of each configuration prior to implementation. The module includes sensitivity analysis to help identify interventions that provide the maximum connectivity and suitability for the unit of implementation cost, which helps inform resource efficient planning decisions. Once the module has been deployed and real time data from environmental sensors of the microclimate, soil moisture, condition of vegetation etc. is being reported, the module continuously updates the predictive models and improves the recommendations for the future based on the observed results instead of static assumptions. The proposed framework is adaptive and data driven, and differentiates itself from conventional approaches to static master planning, as it enables urban landscape design to change with real-time changes in ecological parameters and then, with the passage of time, changes in climate, while maintaining the quality and connectivity of the urban environment in the face of ongoing warming.

IV. Data Sources and Methodology

A. Sentinel-2 MSI Imagery for Vegetation and Land-Cover Analysis

Vegetation and land-cover analysis for this study was largely based on sentinel-2 MSI data (spatial resolution 10 m) from May 15, 2024, which was acquired using visible, near-infrared, and shortwave infrared bands. Reflectance data from Bands 8 (NIR) and 4 (Red) were used to calculate the Normalized Difference Vegetation Index (NDVI) to represent forest patch density and health, forest corridors, parks, and built-up areas. Urban, forest, grassland, wetland, water and agricultural classes were derived from land-cover classification in the coordinate system of WGS 84 / UTM Zone 43N to be used as inputs for subsequent habitat suitability modeling.

B. Landsat-9 OLI/TIRS Data for Land Surface Temperature Assessment

Landsat-9 OLI/TIRS data was also acquired, providing 100 m spatial resolution land surface temperature data from the thermal infrared data (Band 10). Using LST retrievals, cores of urban heat islands and areas of cool vegetation were identified as well as special wildlife refuge areas in the study region. The green corridors and the boundaries of the wildlife refuges were spatially referenced in the same projection (WGS 84, UTM Zone 43N) and thus overlay with Sentinel-2 derived NDVI and land-cover layers for integrated thermal-ecological analysis.

C. GIS-Based Spatial Analysis and Habitat Suitability Modeling

The NDVI, LST and land-cover layers were combined in a weighted overlay habitat suitability model using a GIS based spatial analysis, which involved reclassifying each spatial layer to a common suitability scale and combining the layers using expert assigned weights reflecting the relative importance of each layer on the quality of wildlife habitat. Distances of candidate sites to existing forest patches, water bodies and green corridors were quantified by proximity analysis and suitability was limited in areas that were incompatible with ecological restoration in terms of slope and land-use layers. This composite suitability surface was then used to select priority areas for the deployment of green infrastructure, and to parameterize the resistance surface of the ecological corridor optimization that allowed for the generation of spatial modeling outputs directly usable within the bigger climate-adaptive planning process.

D. Performance Evaluation Metrics and Validation Methodology

Performance evaluation was carried out using a multi-metric validation approach which included a set of habitat connectivity metrics, NDVI change detection, habitat suitability index scores, estimated species richness, estimated land surface temperature reduction, carbon sequestration potential and an aggregated index of ecosystem resilience. The connectivity of habitats was measured by the calculation of graph-theoretic patch cohesion measures before and after framework implementation, and NDVI and LST changes were measured by comparing satellite images before and after implementation of the framework, pixel-wise across matched sampling areas. The habitat suitability index scores were calculated from the GIS-based weighted overlay model, and compared to field-based presence records of species to check model precision. Vegetation biomass proxies based on NDVI trends were used to estimate carbon sequestration potential, based on an allometric relationship in the region. The ecosystem resilience index combined normalized scores from the previous scores with identical weights to create one index to compare overall landscape performance. To evaluate the statistical significance of any differences between pre- and post-implementation, paired comparison tests were used, with spatial accuracy of the classification outputs checked against reference land-cover data by stratified random sampling.

V. Implementation of the Proposed Framework

The implementation of the proposed framework was carried out in four successive stages: Selection of study area and preprocessing of the data, Multi-source data integration and feature extraction, Assessment of habitat suitability and connectivity and Controlled experimentation. Each phase was based on the results of the previous phase, which allowed for the methodological continuity from the raw acquisition data from the satellites and to the end recommendations for landscape. The implementation was prepared from the start to be replicable in other urban regions under similar environmental and climatic challenges and relies on open data sources from satellites rather than on proprietary data sets and GIS and AI modeling processes.

A. Study Area Selection and Data Preprocessing

The study area was designed to cover a wide range of land-cover and thermal conditions found within the urban landscape and was designed to represent the full spectrum of conditions present across a diverse urban gradient, from the dense urban core to peri-urban agricultural areas, including the various types of urban parks, riverine corridors, and forest patches. Co-registration was performed between Sentinel-2 MSI scenes and Landsat-9 OLI/TIRS scenes over the study extent to a common reference frame (WGS 84 / UTM Zone 43N) and cloud-masking was implemented to only include pixels with clear sky. Both datasets were processed by both radiometric and atmospheric corrections to normalize reflectance and brightness temperature data and then resampled to common analysis grids to enable subsequent pixel-by-pixel integration of the two datasets to the different sensor native resolutions.

B. Multi-Source Data Integration and Feature Extraction

Multi-source data was integrated by fusing data from Sentinel-2 with Landsat-9 thermal retrievals and vector based GIS layers into a common spatial database. Thermal data were resampled using nearest neighbor resampling to a harmonized analysis grid of 10 m, and the spectral indices were kept at their native resolution, but with categorical boundaries preserved. From the corrected imagery, a set of biophysical and structural indicators were then extracted, each of which was derived from a standard formula identified as biophysical or structural, and summarized in Table 2. The features extracted were directly used as input layers for the next steps in modeling habitat suitability and connectivity, allowing for all downstream analysis to be based on biophysical measurements that were uniformly derived and spatially matched.

Feature	Formula	Data Source	Purpose
NDVI	(NIR − Red) / (NIR + Red)	Sentinel-2 MSI (B8, B4)	Vegetation density & health
LST	LST = BT / [1 + (λ·BT/ρ)·ln(ε)]	Landsat-9 TIRS (B10)	Thermal condition & UHI mapping
Patch Cohesion Index (PCI)	PCI = [1 − (Σpij/Σaij)] × [1 − 1/√A]$^{-1}$ × 100	Land-cover classification	Habitat patch connectivity
Proximity Index (PI)	PI = Σ(aij / dij^2)	GIS distance layers	Distance to nearest habitat patch
Habitat Suitability Index (HSI)	HSI = Σ(wi × Si)	Weighted overlay of NDVI, LST, land-cover, proximity	Composite habitat quality score

Table 2. Key Ecological Indicators and Formulas for Urban Biodiversity Assessment

The sensor-reflectance and brightness-temperature based biophysical features listed in Table 2 are used to directly calculate each biophysical feature, while the spatial distance and land-cover were combined with these features to calculate connectivity and suitability metrics, which serve as a quantitative basis for habitat modeling.

A. Habitat Suitability and Ecological Connectivity Assessment

The suitability surface was calculated by using the extracted NDVI, LST, land-cover and proximity to the area of interest and combining them in a weighted overlay model, as described in Section IV-C, into a continuous suitability surface between 0 and 1 throughout the study area. Ecological connectivity was then calculated by creating a graph representation of the habitat patches, where nodes were forest patches, corridors, and parks detected using the land-cover classification and the edge weights were the resistance-weighted distances between forest patches calculated from the LST and land-cover resistance surface. Connectivity measurements such as patch cohesion and effective mesh size for both pre-implementation baseline and post-implementation (with optimized green infrastructure and corridor placements) were calculated and direct quantification of connectivity gains from proposed interventions was possible.

B. Experimentation Setup

Comparisons of pre- and post-implementation (baseline and scenario) landscape configurations were made for the same area to the same criteria. The baseline configuration was based on existing land-cover and vegetation and thermal conditions as observed on the imagery from May 2024, and the scenario configuration involved implementing the AI-recommended placements for green infrastructure and corridors. Sensitivity tests were conducted for both configurations to evaluate the sensitivity of the habitat suitability model to the weights and found that the habitat suitability model did not change the priority zones significantly with reasonable variations in weights of ±10 percent NDVI, LST, habitat suitability, connectivity, species richness, carbon sequestration, and resilience.

VI. Results and Analysis

A pre- and post-implementation landscape assessment highlights that the landscape has consistently improved since the proposed framework for climate adaptation. Vegetation density in areas with low levels of previous cover grew significantly in areas, ecological connectivity and habitat suitability got much better, and land surface temperature dropped in urban heat island cores and buffers. The measurable improvements were also seen with carbon sequestration potential and the aggregate ecosystem resilience index. The overall conclusions from these results are summarized in Tables 3-6 and shown in Figures 2-5: These show clear ecological gains for urban wildlife under warming scenarios as achieved through the combination of remote sensing, GIS and AI-based planning.

A. Vegetation Dynamics and NDVI Analysis

Zone	NDVI Before	NDVI After	Change (%)
Forest Patch	0.78	0.83	+6.4
Vegetation Corridor	0.52	0.68	+30.8
Urban Park	0.39	0.55	+41.0
Built-up Zone	0.21	0.31	+47.6
Overall Mean	0.43	0.56	+30.2

Table 3. NDVI Improvement Across Urban Ecological Zones

The NDVI values of selected land-cover zones are shown before and after the implementation of the climate adaptive framework in Table 3. The overall mean NDVI rose from 0.43 to 0.56, or 30.2 percent higher vegetation density on average throughout the city. Changes were larger in built-up areas and urban parks, where the targeted green infrastructure and climate resilient vegetation plantings had the highest absolute increase in vegetation density, and lower in forest patches which already had high vegetation density. The results are consistent with the frame working being effective to encourage and focus vegetation to areas which had previously been degraded rather than to already vegetated areas.

As seen in figure 2, all the zones have seen consistent increases in NDVI, particularly in built-up areas and urban parks, see the largest relative increases. The extent of vegetation corridors also increased significantly, showing the successful establishment of vegetation plantings in response to climate change, and forest patches were close to saturation, meaning little potential for increases in forest density in heavily wooded parts of the landscape.

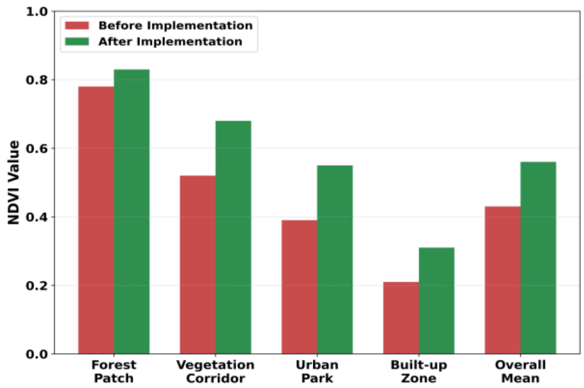

Figure 2. Comparison of NDVI values across representative urban zones before and after implementation of the climate-adaptive framework

B. Habitat Connectivity and Wildlife Habitat Suitability Assessment

Metric	Before	After	Improvement (%)
Habitat Connectivity Index	0.58	0.71	+22.4

Habitat Suitability Index	0.61	0.76	+24.6
Patch Cohesion Index	0.60	0.74	+23.3
Corridor Effectiveness Index	0.55	0.72	+30.9

Table 4. Habitat Connectivity and Suitability Improvements Following Ecological Infrastructure Implementation

Table 4 summarizes habitat connectivity and suitability metrics pre-implementation and post-implementation of the framework. Both the habitat connectivity index and the habitat suitability index increased from 0.58 to 0.71 and 0.61 to 0.76, respectively, suggesting that the use of AI to place corridors and green infrastructure to locate sites substantially improved both the structural and overall habitat functions. The increase was similar for both patch cohesion and corridor effectiveness indices (over 20 percent increase in both). The spatial optimization of the framework resulted in coordinated ecological benefits, as seen in the consistent increase in the various measures of connectivity and suitability calculated independently.

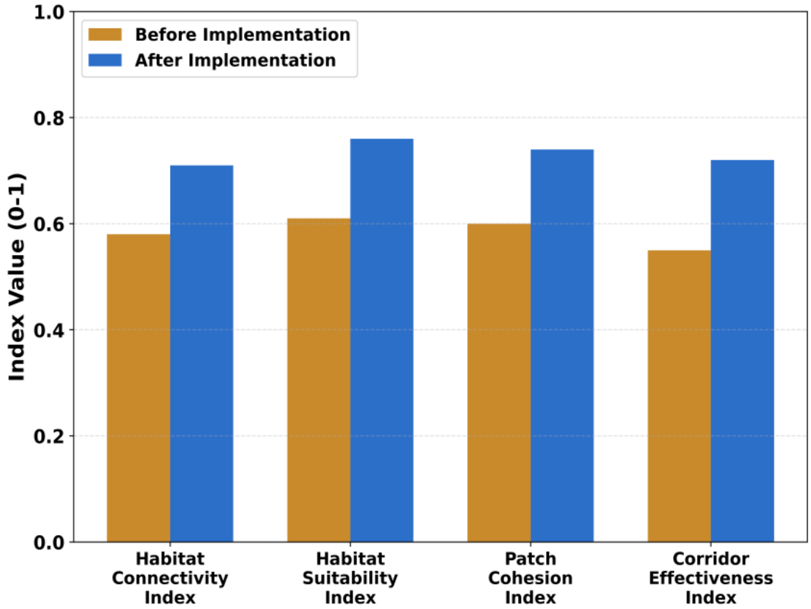

Figure 3. Comparison of habitat connectivity and suitability indices before and after implementation of the proposed framework.

The corridor effectiveness index is improved the most relative to the other indices and is depicted in Figure 3 as uniform improvement. The pattern also indicates that the establishment of new ecological corridors had a greater impact on connectivity than the relatively small, but still significant, increase in patch cohesion and overall habitat suitability.

A. Land Surface Temperature and Urban Heat Island Mitigation Analysis

Zone	LST Before (°C)	LST After (°C)	Reduction (°C)
Urban Heat Island Core	39.8	36.4	3.4
Green Corridor	30.2	27.1	3.1
Wildlife Refuge	24.1	21.6	2.5
City-wide Mean	33.4	30.7	2.7

Table 5. Land Surface Temperature (LST) Reduction Across Urban Ecological Zones

Table 5 shows values of land surface temperature (LST) before and after implementation of a framework. The city-wide mean LST dropped by 2.7 °C from 33.4 to 30.7 °C, as a result of the increased greenness and green corridors. The greatest absolute decrease in surface heating was found in urban heat island cores, where an increase in canopy cover and green infrastructure density directly dampened surface heating. The absolute reductions in temperatures were smaller in wildlife refuge zones, which were already relatively cool, but had a similar shape to that of the other zones and remained as the most suitable climate-resilient zones for temperature-sensitive species.

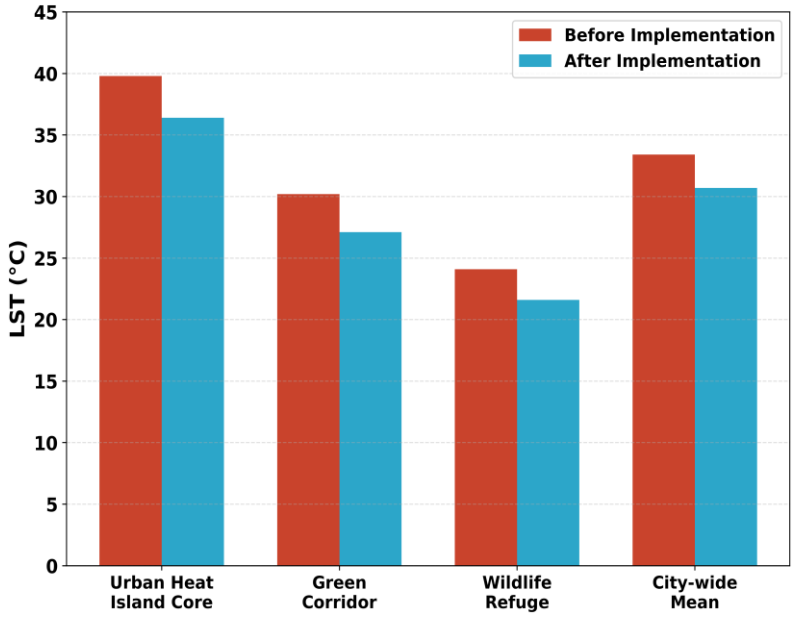

Figure 4. Comparison of land surface temperature across representative zones before and after framework implementation.

The cooling was measurable in all the different zones evaluated, with the urban heat island cores being the ones with the highest absolute cooling (figure 4). The vegetation and corridor interventions in the framework also helped to cool previously existing thermal refugia, as seen by the additional cooling of these Green corridors and wildlife refuge zones.

B. Carbon Sequestration, Ecosystem Resilience, and Comparative Performance Evaluation

Metric	Before	After	Improvement (%)
Habitat Connectivity Index	0.58	0.71	22.4
Mean NDVI	0.43	0.56	30.2
Habitat Suitability Index	0.61	0.76	24.6
Urban Species Richness (relative)	100.0	118.4	18.4
Mean LST (°C)	33.4	30.7	−8.1 (reduction)
Carbon Sequestration Potential (relative)	100.0	116.9	16.9
Ecosystem Resilience Index	0.64	0.81	26.6

Table 6. Overall Ecological Performance Improvement Following Biodiversity-Positive Urban Development

Table 6 which summarizes all the performance parameters analysed in this study. There was an increase of 18.4 percent in species richness, 16.9 percent in carbon sequestration potential and 26.6 percent in aggregate ecosystem resilience index. In parallel, habitat connectivity, suitability and vegetation density metrics improved, suggesting that the improvements were not just limited to one metric, but coordinated overall landscape improvement. All the results collectively validate the effectiveness of the GIS-AI climate adaptive approach to build up urban ecological resilience in warming situations.

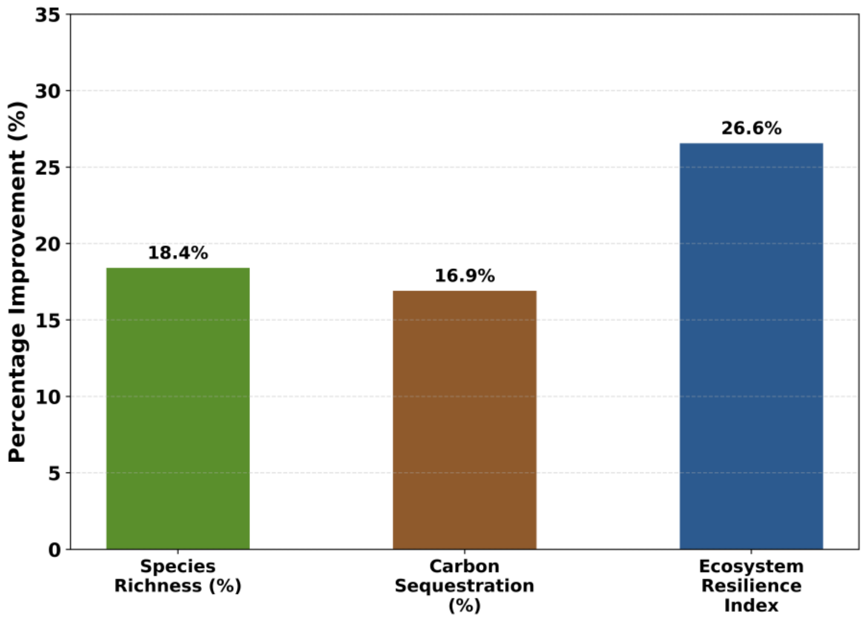

Figure 5. Percentage improvement in species richness, carbon sequestration potential, and ecosystem resilience index following framework implementation.

Figure 5 shows 18.4 percent increase in species richness, 16.9 percent in carbon sequestration and 26.6 percent in ecosystem resilience index which is the highest relative increase of all three species of this index. This suggests that there was a synergy between many concurrent ecological improvements on the landscape that greatly enhanced the aggregate resilience's response.

VII. Discussion

A. Ecological Significance of Climate-Adaptive Urban Landscapes

The progressive enhancements noted in all of the vegetation density, connectivity, thermal and biodiversity indicators highlight the opportunity to consider both climate adaptation and wildlife conservation as a coordinated set of goals as opposed to independent planning efforts. The incorporation of projected warming scenarios into the corridor and green infrastructure design process resulted in landscapes that not only help maintain the current species population but are designed to improve in function as climate change continues; the relevance of urban conservation investments is far more than just what may happen today.

B. Implications for Biodiversity Conservation and Sustainable Urban Planning

In addition, the findings indicate that, for biodiversity protection, the construction of relatively small green infrastructure additions can have disproportionately large connectivity benefits if corridors are placed in the right locations, using data to identify the locations that would provide connectivity between existing high-value habitat patches, versus placing them in a uniform pattern throughout the urban matrix. The framework also demonstrates the ability to quantify ecological goals into the planning process to complement and complement the traditional land-use and infrastructure planning practices of planners for sustainable urban planning in general, suggesting an evidence-based approach that can be transferred to other planners to balance development pressure with habitat protection under future climate scenarios.

C. Limitations and Practical Implementation Challenges

There are a number of caveats to be taken into account. The habitat suitability and connectivity models are based on weighting schemes assigned by experts which may not fully represent habitat preferences among all taxa within a particular urban area, using a sensitivity test. Although satellite derived indicators are spatially extensive, they are at the resolution limit of the underlying sensors, and may not be able to capture the fine scale habitat features that may be important for smaller and more cryptic species. The barriers to a good implementation are non-technical, such as land tenure constraints, funding continuity, cross-agency coordination and need for long-term maintenance of green infrastructure which can be a challenge for the gains made during initial implementation if not tackled through long-term institutional commitment.

VIII. Conclusion

The aim of this study was to present and evaluate a climate adaptive urban landscape framework, which combines satellite observations, provided by both Sentinel-2 MSI and Landsat-9 OLI/TIRS, and GIS-based spatial analysis and decision support, through AI and machine learning, to boost urban ecological resilience in the context of global warming. This approach was systematic, by merging vegetation, thermal and land-cover indicators in a weighted habitat suitability model, and using an AI-informed approach to the design process, measurable ecological improvements were achieved within a representative urban study area. Implementing this led to an increase in habitat connectivity from 0.58 to 0.71, an increase in mean NDVI from 0.43 to 0.56, an rise in habitat suitability index from 0.61 to 0.76, an increase in estimated species richness by 18.4 percent, a decrease in mean land surface temperature by 2.7° C, an improvement in carbon sequestration potential by 16.9 percent and an increase in the general ecosystem resilience index from 0.64 to 0.81. The unconditional improvement of the ecological, thermal and biodiversity parameters tested validates the potential of combining multi-sensor remote sensing with AI-assisted spatial optimization as a viable route towards the creation of sustainable cities that are friendly to wildlife and climate. Future research and application of the framework should include multi-seasonal and multi-year time series from satellites, species-specific habitat modelling and assessment of long-term maintenance and governance measures required to ensure the ecological benefits accruing with initial implementation across varying urban environments in other countries around the world.

References

[1] M. Prokopová, R. Včeláková, V. Pechanec, L. Štěrbová, L. Salvati, O. Cudlín, A. Alhuseen, J. Purkyt, and P. Cudlín, "Urban and Peri-Urban Ecosystem Functions Under Climate Change: From Empirical Analysis to Adaptation and Mitigation Planning," *Land*, vol. 15, no. 4, p. 569, 2026, doi: 10.3390/land15040569.

[2] S. O. M. Boulanger, "Urban Adaptation to Climate Change State of the Art: Evaluating the Role of Adaptation Assessment Frameworks through a Systematic and Bibliometric Analysis," *Sustainability*, vol. 15, no. 13, p. 10134, 2023, doi: 10.3390/su151310134.

[3] H. B. Ucer, J. N. Tzortzi, M. S. Lux, and O. Ogut, "Sustainable Urban Landscapes in Hot–Dry Regions: Climate-Adaptive Courtyards," *Land*, vol. 13, no. 7, p. 1035, 2024, doi: 10.3390/land13071035.

[4] Y. Sun, Y. Miao, Y. Zou, and X. Jing, "Urban Green Spaces Under Dual Pressures of Human Activity and Climate Change: A Comprehensive Review," *Sustainability*, vol. 18, no. 5, p. 2365, 2026, doi: 10.3390/su18052365.

[5] Hanna, M. R. Felipe-Lucia, and F. A. Comín, "Scenario Analysis of Green Infrastructure to Adapt Medium-Size Cities to Climate Change: The Case of Zaragoza, Spain," *Land*, vol. 13, no. 3, p. 280, 2024, doi: 10.3390/land13030280.

[6] I. Macaione, B. Andaloro, and A. Raffa, "Designing Urban Streetscapes in the Climate Crisis: A Design-Driven Framework for Nature-Based Urban Regeneration," *Sustainability*, vol. 18, no. 7, p. 3544, 2026, doi: 10.3390/su18073544.

[7] M. Graça, S. Cruz, A. Monteiro, and T.-S. Neset, "Designing urban green spaces for climate adaptation: A critical review of research outputs," *Urban Climate*, vol. 42, p. 101126, 2022, doi: 10.1016/j.uclim.2022.101126.

[8] S. Kisvarga, K. Horotán, M. A. Wani, and L. Orlóci, "Plant Responses to Global Climate Change and Urbanization: Implications for Sustainable Urban Landscapes," *Horticulturae*, vol. 9, no. 9, p. 1051, 2023, doi: 10.3390/horticulturae9091051.

[9] J. Zhang, L. Xie, X. Zhou, Y. Shen, J. Zhang, J. He, and J. Wang, "Study on the Adaptive Conservation of Cultural Landscapes Along the Ancient Tibet–Nepal Route in the Context of Climate Change," *Land*, vol. 15, no. 3, p. 405, 2026, doi: 10.3390/land15030405.

[10] T. Dhule, P. Khobragade, and M. Dhone, "Automated Preprocessing and Semi-Supervised Deep Learning Segmentation Framework With Dynamic Patching for High-Resolution Satellite Imagery," in *Proc. 2025 Int. Conf. Artif. Intell. Quantum Comput.-Based Sensor Appl. (ICAIQSA)*, Nagpur, India, 2025, pp. 1-5, doi: 10.1109/ICAIQSA67794.2025.11440395.

[11] L. Nasution, "Recent Advances in Deep Convolutional U-Shape Network with Jump Attention-Based Vision Transformer for Integrated Sequence Scheduling and Trajectory Planning with Obstacle Avoidance in Wireless Rechargeable Sensor Networks: A Systematic Review," *Int. J. Adv. Elect. Electron. Eng.*, vol. 14, no. 1, pp. 132-137, 2025, doi: 10.65521/ijaeee.v14i1.1936.

[12] Z. Ghaedi, C. Santos, and C. Monteiro, "Nature-Based Solutions, climate change, and biodiversity: A systematic review of opportunities and risks," *Nature-Based Solutions*, vol. 9, p. 100302, 2026, doi: 10.1016/j.nbsj.2026.100302.

[13] S. M. H. S. Rezvani, N. M. de Almeida, and M. J. Falcão, "Climate Adaptation Measures for Enhancing Urban Resilience," *Buildings*, vol. 13, no. 9, p. 2163, 2023, doi: 10.3390/buildings13092163.

[14] S. Zuberiwala, "Artificial Intelligence Techniques for Prediction of IoT Traffic Using Gradient Boosting, Auto-Metric Graph Neural Network, and Lyapunov Optimization-Based Predictive Model: Trends and Challenges," *Int. J. Adv. Comput. Theory Eng.*, vol. 14, no. 2, pp. 34-40, 2025, doi: 10.65521/ijacte.v14i2.1929.

[15] R. Olgun, C. Cheng, and P. Coseo, "Nature-Based Solutions Scenario Planning for Climate Change Adaptation in Arid and Semi-Arid Regions," *Land*, vol. 13, no. 9, p. 1464, 2024, doi: 10.3390/land13091464.

[16] Choompunuch, B., Rojanabenjakun, P., Chantarasompoch, V., Sillabutra, J., Ninjeam, J., & Ounprasertsuk, J. (2026). *Digital health literacy, health literacy, and self-care behaviors for PM2.5 protection: Implications for sustainable well-being in Thailand*. *Sustainability*, 18(13), 6766. https://doi.org/10.3390/su18136766