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OPTIMIZED ECOLOGICAL NETWORK APPROACH OF HIGHLY URBANIZED CITIES: THE CASE OF ADANA CITY

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ABSTRACT:

One of the most significant challenges in urban areas, where the process of rapid urban expansion takes place, is the loss of agricultural lands and natural habitats. The conversion of these areas into residential and commercial zones leads to a decline in urban biodiversity and the progressive loss of vital habitat areas. Analyzing habitat connectivity and conducting landscape measurements provide valuable insights for the development of land use and management strategies, enhancing our understanding of the spatial structure of the landscape, and directing conservation efforts. Incorporating measures such as green corridors and landscape connection networks into urban planning management becomes crucial in order to mitigate the adverse effects of habitat fragmentation and enhance ecosystem resilience within cities. Remote sensing techniques offer opportunities to create habitat connectivity models that enable the quantitative and qualitative identification of fragmented habitat patches. These models serve as tools to evaluate the effectiveness of conservation measures and monitor the potential impacts of future land use changes on habitat networks. Within this context, an optimized approach to habitat connectivity is presented, aiming to contribute to landscape planning and ecological-based studies in a city with undergoing rapid urbanization like Adana. By identifying degraded areas and introducing new habitat patches, a significant improvement in the connectivity of the habitat network has been observed. The findings indicated that the addition of new habitat patches to degraded areas can substantially enhance the city's overall habitat connectivity.

1. INTRODUCTION

In the process of rapid urbanization, the urban landscape continuously invades the ecological landscape and suppresses the integrity of the ecosystem (Li et al., 2011; Fahrig and McGill, 2019). In urban areas, habitat patches are reduced, landscape fragmentation is intensified, and the connectivity between habitat patches is reduced, resulting in the destruction of ecosystem structure, which prevents the circulation of ecological flow and weakens the function of urban ecosystem (Zhou and Wang, 2011).

Urban ecological infrastructure usually consists of natural or semi-natural landscapes such as forests, grasslands and water, which secure sustainable ecosystem services to maintain the integrity and functionality of urban ecosystems (Li et al., 2017). Planning and optimization of urban ecological infrastructure can be achieved through urban sprawl control (Gavrilidis et al., 2019), biodiversity conservation (Connop et al., 2016), climate adaptation (Norton et al., 2015), flood risk management (Alves et al., 2019) and air pollution control (Tiwari et al., 2019).

In order to sustain ecological processes in urban landscapes, it is necessary to connect important ecological patches because these patches can be regarded as ecological resources in cities. Urban landscapes not only provide habitat for species, but also have high ecosystem service value at the scale of regional ecology. Maintaining connectivity between ecological resources helps fulfill multiple objectives: (1) genetic exchange, (2) individual migrations, (3) promoting seed dispersal, (4) recovery and recolonization after disturbance, (5) improving food supply by strengthening pollination services, (6) mitigating the impacts of climate change on biodiversity, and (7) nutrient cycling (McRae and Beier, 2007; Dickson et al., 2019; Hilty et al., 2020). Connectivity in urban landscapes enhances exchanges between ecological resources and maintains ecosystem stability, which in turn supports regional ecological sustainability (Hong et al., 2017).

In this study, the city of Adana and its surroundings, selected as an example of uneven and rapid urbanization, were evaluated in terms of landscape pattern using graph theory and connectivity analysis. IIC metric was applied using forested areas, urban green areas, and water surfaces from a land cover/land use map. These elements were likely chosen because they are important for maintaining ecological connectivity and promoting biodiversity within a landscape.

2. MATERIAL AND METHOD

The methodology used in this study focuses on addressing the challenges of urbanization and habitat loss in Adana, Turkey. The study aims to contribute to landscape planning and ecological-based studies by presenting an optimized habitat connectivity approach.

This study was carried out in 4 steps:
1. Obtaining the Land Use and Land Cover (LULC) map,
2. Revealing the urban ecological network,
3. Determination of degraded areas in the study area,
4. Obtaining an optimized LULC map (Figure 1).

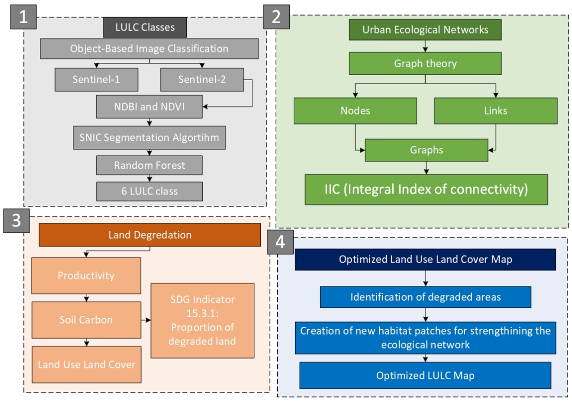

Figure 1. Outline of the study

2.1 Study Area

Study area is located in the southern part of Turkey. Adana is the seventh largest city in Turkey in terms of urbanization and population. According to the 2021 data from TUIK (Turkish Statistical Institute), the city has a population of 2,263,373. In this context, the five major districts with the highest urbanization trend in Adana have been selected as the study area. The selection of these districts allows examination of the impacts of urbanization on their specific vulnerabilities to ecological degradation (Figure 2).

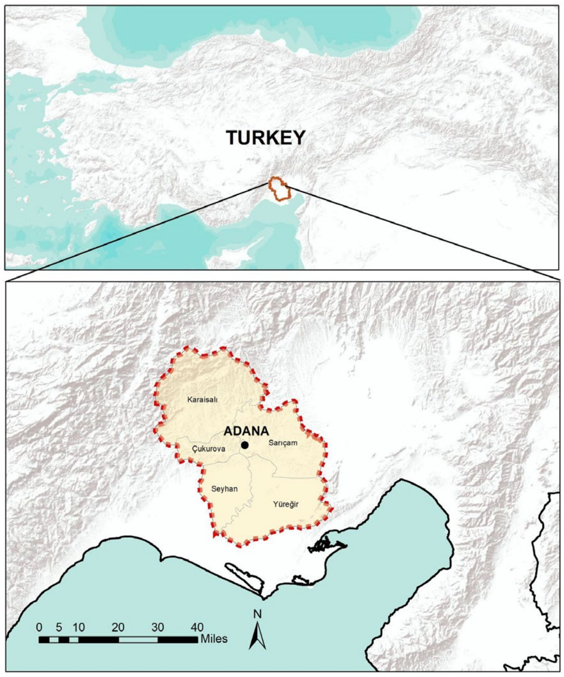

Figure 2. Location of study area

2.2 Method

2.2.1 LULC Classes: In order to reveal ecological networks in study area, land cover and land use map was generated using object-based classification with Google Earth Engine cloud platform. A 10-meter resolution Sentinel 2 image was used for this purpose. The Sentinel-2 L2 data were downloaded from scihub and processed by running sen2cor. Additionally, GEE Cloud-mask was implemented where it was necessary.

The S2 cloud probability is generated using the Sentinel2-cloud-detector library, and all bands are resampled to 10m resolution before applying the gradient boost base algorithm. The resulting probability values are scaled and stored as UINT8, with higher values indicating a greater likelihood of clouds or highly reflective surfaces. Areas without complete data are masked out. Additional indices were used to assist in the classification of cloud-free Sentinel-2 images for the year 2021. These indices are NDVI and NDBI. NDVI is generally used for mapping changes in land cover this index provides a significant improvement in classification accuracy for LULC. NDBI highlights the difference between bare soil and built-up areas, allowing us to identify built-up areas. The object-based classification was performed using the SNIC (Simple Non-Iterative Clustering) algorithm on Google Earth Engine. The LULC map has 6 classes, including, Wetlands, Open Areas, Forest, Agricultural Areas, Settlements, and Urban Green Spaces (Kurt et al., 2022) (Figure 3).

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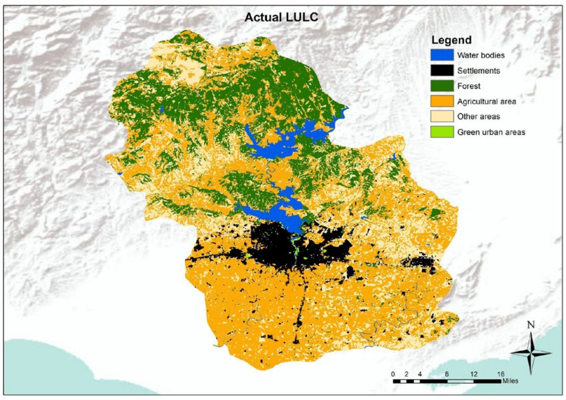

Figure 3. LULC classes

2.2.2 Urban Ecological Network and Graph Theory: In remote sensing, graph theory is commonly used in the form of a graph-based image analysis (GBIA). GBIA represents an image as a graph, where each pixel or segment in the image is represented as a node or vertex in the graph, and the edges between them represent the spatial relationships between these features. By analyzing the topology of these connections, researchers can measure the degree of similarity between different features and identify potential spatial patterns and cluster.

GBIA-based graph theory enables various remote sensing applications such as land cover classification, object detection and tracking, and change detection. For instance, it can be utilized to establish the connections between different land types in land cover classification and to analyze the interconnectedness of diverse landscape elements like habitat patches and water surfaces (Liu et al., 2018).

Graph theory, as a mathematical framework, is employed to analyze the interrelationships among various entities, including habitats. It has also been extensively utilized in modeling habitat network connectivity. This process involves identifying and segmenting habitat network patches within the landscape into smaller units, followed by analyzing the interconnections among these units. The fragmentation index, which accounts for patch number, average size, and edge density, is commonly employed as a measurement unit in this theory. This approach facilitates a more analytical approach to addressing issues such as species distribution and identifying ecological units affected by habitat fragmentation, enabling studies such as conservation planning and determination of management strategies to be conducted in a more systematic manner.

In line with the studies and as stated in the Graphab software, it can be said that one of the most appropriate metrics for urban green spaces is Integral Index of Connectivity (IIC) (Zhang & Wang, 2006; Saura & Pascual-Hortal, 2007; Alshafei & Righelato, 2022; Guo et al., 2022). This metric is one of the most appropriate and widely used metrics for assessing the connectivity and isolation of urban green spaces. While other connectivity metrics consider the connectivity of habitats as either present or absent, IIC metric calculates the quality of the connections between habitats. This quality is based analysis on factors such as strength, width, corridor length, vulnerability, and other related factors of the connections between habitats.

$$IIC = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\left((a_i \cdot a_j)/1+nl_{ij})\right)}{A_L^2} \quad (1)$$

where A = Area of the study zone
n = Number of patches
nl_{ij} = Number of links in the shortest path between patches i and j.
a = Brake on movement distance

In this context, GRAPHAB 2.8 software was used to optimize ecological networks in Adana province and IIC was chosen as the connectivity metric.

2.2.3 Land Degradation: In regions facing rapid urbanization, land degradation is experienced by the construction of buildings and infrastructures instead of agricultural areas and green urban areas. This often hinders the use of ecosystem services in many ways, from reduced agricultural productivity to reduced food production and destruction of ecological habitats (Baumber et al., 2020).

Trends.earth is an open-source tool that allows users to assess and monitor the impacts of land use changes on ecosystem services such as water quality, carbon stock and biodiversity. The tool uses satellite imagery and machine learning algorithms to analyze land use changes and for sustainable land management.

Dedicated to SDG indicator 15.3.1, these 3 sub-indicators are used to identify degraded areas:

1. Vegetation productivity
2. Land cover
3. Soil organic carbon (Gonzalez-Roglich et al., 2019) (Figure 4).

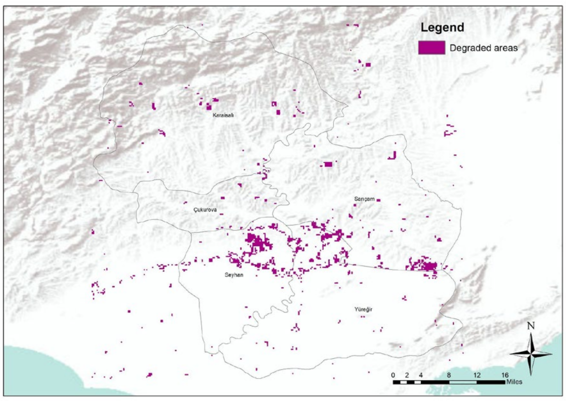

Figure 4. Degraded areas in study area

3. RESULTS

Landscape connectivity analysis was carried out within the scope of Rivers, Forests and Urban green areas, which are obtained from the LULC map. A probabilistic link model was created using a set of habitat units and links produced as input data, and the IIC metric mapped by interpolating the values assigned to the nodes or components.

The IIC metric is recognized as a habitat availability index due to its integration of topological features, such as network connectivity, with attributes pertaining to the extent of forest habitat (Pascual-Hortal and Saura, 2006). Specifically, the IIC-based habitat availability index may classify a landscape containing two large isolated forest patches (e.g., 1,000 ha) as more connected than other landscapes consisting of two interconnected yet smaller patches (e.g., 10 ha). This distinction arises from the fact that the larger patches can encompass all smaller ones, thereby providing a more extensive habitat. The availability of habitat for a given species can be diminished by either poorly connected patches or highly connected yet scarce habitat patches. Furthermore, the IIC metric facilitates the detection of unfavorable changes impacting the forest landscape, encompassing aspects such as connectivity loss, reduction in forest area, or alterations within the forest itself (Pascual-Hortal and Saura, 2006). In Figure 5, it can be seen that the presence of a significant habitat within the forest patches located in the north of the study area that increases the IIC metric's value.

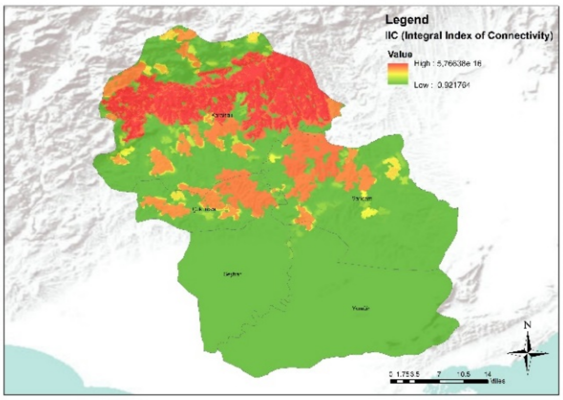

Figure 5. Calculated IIC connectivity metric

In order to obtain an optimized land cover map, a series of locations that are believed to contribute to a specific gain in connectivity are tested. Subsequently, new habitat patches are generated based on these locations. These locations were limited to the degraded areas within the study area. Initially, the selected global connectivity metric is computed, followed by the virtual addition of a patch and the establishment of links between this patch and existing ones. In the case of a thresholded graph, only patches surpassing the predefined link distance threshold are connected. Once all locations have included testing, the location that produces the most substantial increase in patch metric value is confirmed. This iterative process continues until the desired number of additional patches is reached, encompassing elements that have been previously added at each step. Figure 6 shows the existing patches along with an additional 100 habitat patches that have been added to enhance the IIC connectivity metric.

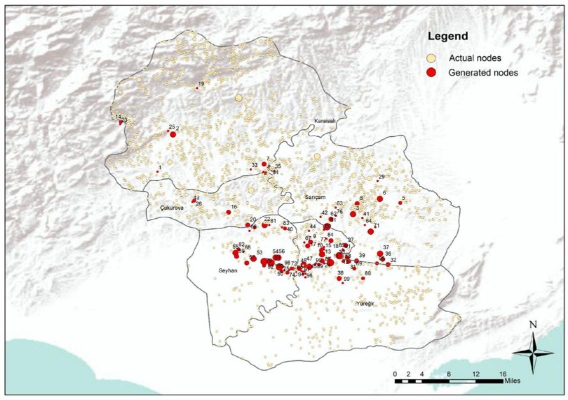

Figure 6. Existing nodes and generated nodes representing habitat patches

When the updated LULC map is examined with the habitat patches that have been tested and added spatially within the scope of the degraded areas, it is seen that the newly added patches are generally located around the urban areas (Figure 7).

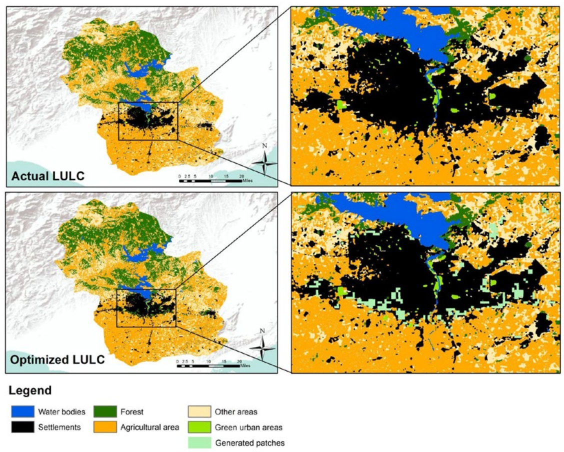

Figure 7. Actual LULC map and optimized LULC map

When the graph given in Figure 8 is examined, it is seen that the added 100 habitat patches have a significant positive effect on the IIC metric. However, it can be seen that the metric did not show a significant increase when the number of added patches reached approximately 80. This finding indicates an important output, as it suggests reaching the maximum capacity of additional patches.

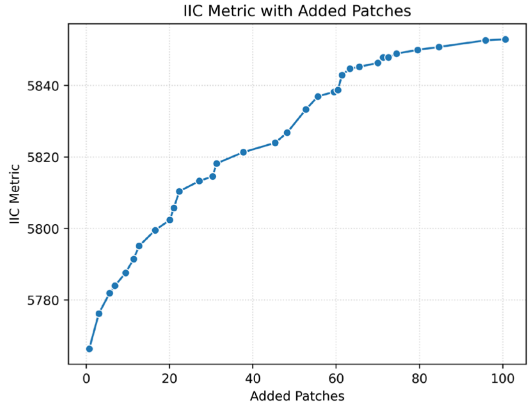

Figure 8. Generated habitat patches and IIC metric value

4. CONCLUSIONS

The disruption of landscape connectivity and the loss of natural land cover due to land degradation pose significant threats to the health and functionality of urban ecological networks, highlighting the importance of addressing these issues for the well-being of both urban ecosystems and human populations.

Adana is experiencing rapid urbanization, and this process result the loss of agricultural land and natural habitats. Urban growth has also affected food security and biodiversity in Adana city. To address these vulnerabilities, habitat connectivity and landscape metrics are crucial in conservation and land-use management planning. Analysis such as wildlife corridors and landscape connectivity networks can enhance habitat connectivity, mitigate fragmentation, and improve ecosystem resilience.

The utilization of remote sensing techniques in identifying habitats and mapping their distribution plays a crucial role in the development of urban habitat connectivity models. The integration of remote sensing applications with habitat network connectivity models holds significant importance in preventing habitat losses through the implementation of effective conservation and management strategies. In study area, an optimized approach to enhance habitat connectivity has been implemented. This study was aimed to contribute to ecologically based studies and facilitate the restoration of degraded areas.

The objective of the study was to enhance habitat network connectivity through the addition of new patches and to develop an optimized land cover map. The results demonstrated a noteworthy improvement in connectivity metrics as a direct outcome of incorporating supplementary habitat patches, signifying enhanced connectivity within the landscape. This outcome underscores the efficiency of the approach in enhancing habitat connectivity. Furthermore, the generation of an optimized land cover map yields valuable insights for conservation planning and management strategies, facilitating the preservation of biodiversity. Further studies are needed which will include future scenarios into the analysis and the dynamics of urban habitat networks can be monitored.

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