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Original Research Article

Measuring the Connectivity of Urban Ecological Network by Using Landscape Metrics

(Case Study: Tehran Municipality District 22)*

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Abstract | Green spaces are generally defined as the physical patches in cities that are measured by the standard indicators per capita. Therefore, the location, abundance, and distribution of green patches in cities are usually not measured on request or based on the qualitative and ecological continuity components; they are systematically reported relying on the quantitative data and standard level per capita. So, green spaces in cities may represent an adequate level based on data and numerical assessments, but considering the social standards, they might not show a standard level of quality; for example, in Tehran Municipality District 22, as a case report in this study, this issue has been observed. The reason might arise from underlying conditions, as in urban planning and the master plan, quantity is mainly the priority, and the quality level has not been defined according to the citizens` living needs and demands. This study aims to identify the ecological weaknesses of the landscape of Tehran Municipality District 22 and overcome the conditions to increase the continuity of the urban ecological networks and thereafter increase the urban physical and social cohesion by connecting the sub-urban green spaces and outlands to the inner urban green spaces by implementing proceedings such as 1. construction of an urban green belt, 2. expanding large green spots, and 3. utilizing natural corridors such as rivers, valleys, and the natural corridors along them The landscape metrics were measured in a four-step process from 2013 to 2020 relying on images captured by Landsat 8 satellite followed by QUick Atmospheric Correction (QUAC); at the next step, the spatial resolution of the images was increased every two years using the panchromatic band and the Gram-Schmidt algorithm, which finally followed by cropping images considering the boundary of Tehran Municipality District 22. The satellite images were processed using ENVI 5.3 remote sensing software, and the images were evaluated in five land cover areas as follows: 1. Bare Land (BL), 2. Vegetation Cover (VC), 3. Water area, 4. Paved Road (PR), and Built-up Land (BUL). The captured images were analyzed using Fragstats 4.2 software after classifying satellite images, followed by measuring the indicators such as "total area/patch", "number of patches", "patch density", "class percentage", "largest patch index", "average patch area", and "adjacency and correlation index". The results showed that the number of patches (NP) has increased at the landscape scale from 1391 patches to 1687 ones between the years of 2013 and 2023, indicating the smaller size of green patches and the loss of continuity in the landscape structure. However, examining the landscape metrics in the vegetation area represents a successful effort in preserving them in recent years, given the constant patch area and the relevant percentage, along with the decrease in the number and density of patches at the class scale, despite an increase in urban construction.

Keywords | *Landscape Ecology, Sustainable Landscape, Landscape Integrity/connectivity, Vegetation Landscape.*

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Introduction| The concept of green space connectivity, which has recently been presented globally, refers to the connections between functionally different green spaces in a region or city, that can be achieved by the connections of green corridors, wildlife corridors, or parks and gardens to each other. Green space continuity aims to create integrative urban ecosystems, increase biodiversity, and improve the quality of urban life. One of the most significant proceedings for increasing the quality of urban green space landscapes is their continuity level, as observing the principles of landscape continuity is one of the essentials in defining urban green landscapes. Over the past half-century, urban spaces, especially residential neighborhoods, have experienced remarkable changes in their evolution and development process as a result of globalization. The expansion of urbanization has notably created a dangerous and vulnerable situation for developing societies, which causes disconnection between humans and their living environment. This gap intensifies the formation of spaces lacking social connections. In fact, despite all the advances of the current century in developing countries like Iran and especially in a capital such as Tehran city, the lack of this vitalizing element in human social life has decreased the quality of urban life more than ever before (Soozanchi & Triveh, 2011).

Human activities, especially unsustainable ones, have had a profound impact on environmental ecosystems. The speed of urbanization has led to the continuous occupation of natural ecological spaces in urban areas, and increased degradation of regional ecological spaces, resulting in habitat loss and landscape fragmentation (Wu et al., 2023). As a result, this fragmentation reduces the area of urban habitats, cuts off important ecological corridors, and weakens landscape connections (Wu et al., 2023; Scolozzi & Geneletti, 2012). In developing countries, this issue is more considerable due to the rapid population growth and unplanned urbanization, together with the higher detrimental effects of development on urban ecological networks and green spaces (Basu & Das, 2023; Jia et al., 2024). To overcome this problem, ecological networks have been constructed in different regions of the world at different spatial scales to lead and restore regional ecological conservation, or even predict future ecological networks under different land use scenarios. However, the aspect of ecosystem integrity and connectivity has rarely been taken into account in order to evaluate the achievements of ecological restoration (Guo et al., 2025). Despite having a suitable foothill natural environment, Tehran, as a capital, has many weaknesses in this regard. Tehran district 22, as a case study here in this study, with an area of about 6000 hectares as a new and modern part in the west of Tehran, could be a possible model for the country relying on a proper design, but it has not benefited that much from this potential, as it has become an emerging issue that is highly influenced by the rapid urban developments and urbanization of Tehran city. This urban area, with an expansion of over one-seventh of Tehran city and as the largest strictly connected to the urban area, has shown rapid growth in recent decades, resulting in restrictions on the development of green space, and consequently, a reduction in urban open spaces, which has led to the replacement of existing green spaces with high-rise buildings in many areas. For instance, many urban gardens, open green spaces, and public spaces have been replaced by dense residential and large commercial areas during the change of urban land use. The systematic field observations have shown that the urban development and the urban land use in recent years have disconnected the inner urban green spaces from those in suburban areas. In addition to the adverse effects on ecological efficiency, this issue has been a great threat to the urban natural identity as well. The literature reviews indicate that the main reason for this issue arises from the adoption of a one-dimensional and partial approach in the macro scale of urban planning, which means inappropriate communication with the other social and environmental structures and functions of the city, besides the lack of continuity and integrity between the components of the green network at the micro scale.

The Significance of the Issue

Landscape architects mainly focus on the aesthetic aspect of the landscape and do not pay attention to the urban ecological features. The combination of green space and hard space can be much more effective than mere aesthetic ones to create an appropriate platform for the restoration of natural ecosystems in the city, in coordination with human activities.

Theoretical Foundations

• Urban ecology

The categories of landscape ecology, green space integrity, and even urban landscape are relatively new disciplines that have not been given serious attention by the authorities, not only in Iran but also in many other countries around the world. In this part, an attempt has been made to concisely deal with these categories by reviewing the research background and literature review.

A number of domestic researchers have worked on this issue, including Saeednia (1994) and Majnoonian (1995); they initially started to address the importance of the inner green spaces of cities in Iran. Years later, the subject was discussed in articles on urban ecological networks in cities. For instance, Khansefid and Aminzadeh published their research on "Investigating the role of ecological networks in the sustainability of the country's metropolitan areas" in 2010 as a beginning for the topic of ecological networks. In other countries, the subject of ecological landscape and the connectivity of urban green spaces had been addressed for several years. Since the early 1990s, ecological networks have played an important role in social and ecological areas, as ecological networks have been introduced as an appropriate approach to improve the ecological and socio-economic values of urban open spaces (Conine et al., 2004). Paying attention to the continuity of urban green spaces, in addition to helping to comply with spatial regulations, strengthens the perception of the urban landscape and creates a sense of vitality and greenery in the minds of citizens (Masnavi & Mohseni Fard Naghani, 2023). Ecological attitudes and approaches are one of the emerging issues in sustainable development and land use planning, especially those in urban planning (Wang et al., 2025). As it appears, most of the world's population is living in cities, resulting in a series of problems like the change of green space utilization for the major cities, as well as the increasing reduction of natural elements and the destruction of the functionality of the urban ecosystem. Most ecologists have usually focused on urban landscape issues. Several studies and research have been conducted in recent years on land use and land cover, especially those addressing urban green spaces, with the approach of landscape ecology and the relevant metrics. For instance, Khansefid (2009), in a research article, implies that to achieve urban sustainability with the approach of landscape ecology, the urban planners are required to consider the integrity and connection between natural and artificial green patches to establish an ecological relationship between the urban spaces and the natural environment. Shieh & Moshref Dehkordi (2013), in a study, have focused on the identity of Shahrekord as a green city with pure, intact nature. The relevant data show that urban expansion in recent years has significantly reduced both the urban and suburban green areas. Man-made construction continues to threaten the urban natural identity. By studying the past status of Sharekord city in different time courses, they found the role of the urban elements contributing to the city's identity. As they have noticed, the continuity of urban green spaces in the past and the observance of spatial criteria used to strengthen the urban sequential perception of the natural landscape, as they had played an important role in increasing the efficiency of urban spaces and promoting the natural identity of this city. Movahed and Tabibian (2018) have emphasized the urban ecological network in urban planning and development programs to address the critical issue of ecological resilience. The main focus of their research was to find a solution for improving the quality of the ecological structure of Mashhad city as the case study. In another study, Jongman & Sluis (2019) referred to the irreplaceable role of ecological networks in forming the concept of the urban green network; they believed that the provided integrity arises from landscape ecology (Jongman & Pungetti 2004).

In another study, Jongman & Pungetti (2004) pointed to the unique role of ecological networks in the process of forming urban green networks and concluded that the process of green networking and its integration is highly related to the landscape ecology (ibid., 2004).

In a similar research, Bai and Guo (2021) proposed the idea that an urban green network is identified and created from the view of ecosystem services and ecological sensitivity; this network aims to improve and protect the sustainability of the ecosystem and lead cities and villages towards green and sustainable development; Moreover, the identification of core urban places would be possible through evaluation of ecosystem services and ecological sensitivity.

Moreover, the acquisition of relatively large-scale lands is an appropriate approach to be considered in the urban master plan under the title of Urban Development and Renovation Reserve, as the lack of integrity and continuity of urban green spaces will prevent the benefits of environmental, social, and economic green spaces in cities. In another study by Saboonchi et al. (2018), the authors pointed out that using an articulated landscape-based approach is of great importance to achieve an integrated green network by connecting the inner and outer green spaces of the cities.

It means that the articulation, with an emphasis on the urban bodies, function, and identity role of the urban green network, is the basis for regulating and organizing green spaces in relation to other urban structures, and an effective element to improve their quality. By creating unified networks of green spaces, the articulation leads to a better perception and understanding of the landscape and natural environment by citizens, which consequently enhances the readability and identity of the city. Noroozi and Bemanian (2019) in a similar research concluded that the constituting elements of landscape have great influence on urban infrastructure, environment, and facilities are the approach to improve urban sustainability and livability indicators for citizens, as it has been shown that, the type of structure, functionality, and distance from green spaces have a direct impact on changing the indicators involved in urban environmental sustainability.

Éva (2011) refers to this issue in a research study that by creating an integrated forestry and cultivation of various plant species in areas with low vegetal density, a significant contribution to the structuring of urban planning would be happen by adopting an urban green space planning, and establishing the quantitative and qualitative development of green spaces to provide the balance between the components of urban green network, and the proportionate physical growth of the city thereby.

In the research by Dormidontova and Belkin (2020), they proposed that the ecological urban approach is carried out by a system of urban open green spaces; as one of the basic principles of building a sustainable urban green network is the continuity of green spaces both between the inner and outer urban spaces and among the residential areas as well. The presence of natural elements within the urban environmental space would be improved through the connection with the biogenic elements of the suburban area.

Therefore, it is believed that instead of socio-economic indicators of urban development, which do not exist today, ecological concepts of the urban ecological landscape can be the basis of urban planning. In a study by Xiaoxia et al. (2022) in Kashgar, China, it has been concluded that in this city, urbanization has inevitably affected the landscape pattern and overall characteristics of the city, and has aggravated urban landscape fragmentation and the destruction of the urban ecological environment, which in turn threatens the urban well-being and biodiversity. They mentioned that urban green space provides habitat for creatures in the city and connects city corridors (Table 1).

• The ecological network connectivity

According to Wood, the ecological connectivity refers to the unimpeded movement of species and the flow of natural processes that sustain life on Earth (Convention on Migratory Species, 2020) and support the persistence of populations, species, communities, and ecosystems (Wood et al., 2022; Beger et al., 2022). Maintaining ecological connectivity, can improve population and community resilience to instabilities such as population fragmentation, and imbalance of green space for residents usually through ecological networks or other similar concepts, such as green infrastructure and green corridors (Hilty et al., 2020), that promote biodiversity, and enhances functionality of ecosystem (Newmark et al., 2017; Truchy et al., 2020; Daigle et al., 2020). Furthermore, ecological network construction is considered a Nature-based solution to social challenges such as climate change adaptation and resilient landscape design (Hilty et al., 2020; Fang et al., 2024; Lafortezza et al., 2018). Urban forests, agricultural lands, prairies, water bodies, and other natural or semi-natural environments are called green spaces (Hofmann & Gerstenberg, 2014). They can improve the well-being of residents, bring various environmental benefits and urban ecosystem profits as a value (Wolch et al., 2014), including reducing noise pollution, reducing the urban heat island (UHI) effect (Estoque et al., 2017), improving urban ecosystem circulation (Livesley et al., 2016), and providing leisure activities for citizens, in an aesthetic, healthy ecosystem (Astell-Burt et al., 2022). Urban green spaces as a "nature-based solution" (Gulsrud et al., 2018) play an important role in ecosystem stability, human health support, and sustainable urban development (Pouso et al., 2021). The decrease and fragmentation of urban green spaces as an adverse outcome of human activities affects the benefits of these green spaces (Kabisch et al., 2015), as they can reduce the area of internal habitats, interrupt important ecological corridors, and weaken landscape connections (Wu et al., 2023). The subject of 'Urban Ecology' is a vibrant research field that is of increasing importance given the growing rate of urbanization worldwide.

Rapid land use changes have altered landscape patterns, as an issue that exacerbated a range of ecological and environmental challenges, including habitat fragmentation (Ramírez-Delgado et al., 2022), biodiversity loss (Cardinale et al., 2012, Kremen et al., 2018), and the degradation of ecosystem services (Zhao et al., 2024). A billion hectares of land worldwide need restoration due to the degradation of ecosystem functions (Peng et al., 2019). The initial projects on environmental protection and restoration used to focus on separate elements and processes, such as mountain protection, water management, farm fertilization, and reclamation of the industrial and mining wasteland (Peng et al., 2019; Guan et al., 2019; Bian et al., 2024), that were ignoring ecosystem integrity and ecological continuity.

The ecological network is a term derived from concepts such as landscape ecology (Turner, 2005), island biogeography (Robert & Edward, 2001), and the theory of source-sink

Table 1. The classification and summary of the research results. Source: Authors.

Research Authors	The Research Result
Khansefid (2009)	Connectivity and integrity between natural and artificial green patches; The urban sustainability
Shieh & Mosharraf Dehkordi (2012)	The role of connectivity: the Urban Identification
Mowahed & Tabibian (2018)	Improving the quality of the ecological structure: Ecological resilience
Bai & Guo (2021)	Creating a green network: Improving and protecting the ecosystem
Jongman & Pungetti (2004)	The concept of urban green network: Coherence resulting from landscape ecology
Ganjipour & Fattahian (2016)	Lack of green space and inappropriate dispersion per capita
Sabounchi et al. (2018)	Consistency and organization of green space
Norouzi & Bemanian (2020)	Effect of structure, functionality, and being distant from green spaces (Accessibility)
Éva (2011)	Opportunities for urban development in relation to the urban green network
Dormidontova &Belkin (2020)	Continuity of urban open spaces as the basic principle of Urboecology
Xiaoxia et al. (2022)	Urban development, landscape fragmentation, and environmental degradation

population dynamics (Hanski, 1999; Baguette et al., 2013). Historically, 'natural heritage' protected areas, networks of 'different landscape types' protected, and spatial ecosystems have all been referred to as 'ecological networks'. Bennett (2004) argues that ecological networks are coherent systems of natural or semi-natural landscape components to achieve an accepted idea of biodiversity conservation. Currently, ecological networks are universally recognized as major habitat patches connected by ecological corridors (Bennett & Mulongoy, 2006), which mostly focus on the spatial arrangement patterns of source and corridor (Yang et al., 2020; Hilty et al., 2020). The ecological network protects the patches resulting from landscape fragmentation and provides a clear pattern of the landscape (Khansefid & Aminzadeh, 2010). In a case study on urban ecological networks and their relationship with a sustainable city in Tehran city as a metropolitan area, this issue has been analyzed by addressing the relevant approach (Aminzadeh & Khansefid, 2010).

The green 'emerald network' model is one of the few models that represents the optimal spatial distribution and arrangement of green spaces in an area (Forman, 2008) that constitutes the following components: 1- The large green patches are of great importance for the protection of aquifers and biodiversity. 2- Watercourses and riverside covers that guarantee the continuity of ecological processes in the land, 3-Connecting large green patches via covered green passages. 4- Small patches and passages distributed throughout the land that provide diversity in the land, and also a connective transit pathway. 5- Small patches and passages around the large patches create a gradient of green areas (Fig. 1).

Ecological green networks, as defined by Forman (2008) and Little (1990) regarding greenways, and the more comprehensive definition by Ahern (1995), indicate their great importance in the urban landscape. Implementing the network thinking of urban spaces forms an integrated urban texture that provides connected physical spaces and activities that result in readability, a sense of orientation, and an integrated urban structure. The expansion of suburban

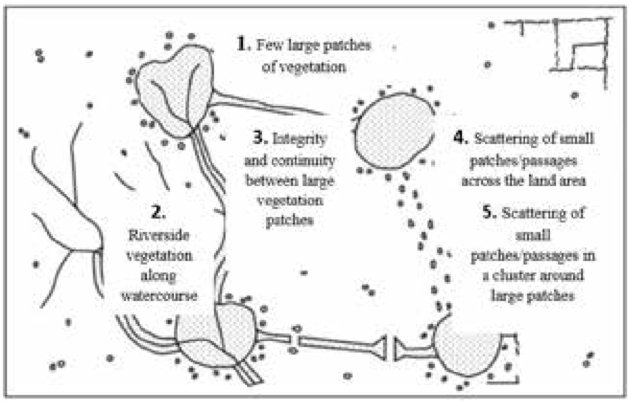

Fig. 1. Green Ecological Network Model. Source: Forman, 2008.

natural green spaces to the inner space of the city by constructing green belts, extending large green patches, use of natural corridors such as river valleys and their spreading, connects the outer city spaces to the inner ones. On the other hand, by connecting smaller green patches within the urban texture through natural and artificial corridors, and also preventing the disconnection of corridors by expanding them along the green patches, a coherent green urban network can be created to be recognized through spreading in various urban spaces, either as one of the main urban layers, to create the basis for the formation of urban spaces, or even as a main part to be integrated with other spaces and layers, not just as a separate added layer (Khansefid, 2009, 154, Kookhaie & Masnavi, 2014).

The physical urban network structure targets the factors that affects the type and manner of connecting the static and dynamic spaces within it; The factors that stablish a suitable combination of continuous integrated spaces, that follows principles such as continuity in the composition of urban spaces, observing spatial hierarchy, human scale, unity in composition, uniformity, the use of contrast, and the creation of spatial diversity, which all lead to the legibility of the urban texture and the possibility of perceiving them (Carmona, 2015). The relationship between sustainable types of urban parameters and the urban morphological elements, including urban open and green spaces, is of great importance in this physical structure (Mobaraki et al., 2025). The landscape metrics can also be proposed in this technical area.

• Landscape metrics

To measure the physical urban network structure, the landscape metrics are being applied in order to describe the spatial structures of the landscape at a specific time, and to provide tools for determining the geometric, physical, and spatial characteristics of a spatial-homogeneous patch in relation to other patches in a mosaic pattern. Landscape metrics are used to quantify the spatial structure of patterns in terms of composition and configuration within a geographic area. These metrics are measurable units of landscape components that allow for the description and quantification of spatial patterns and ecological processes over time and space (Frazier et al., 2019), which can be implemented at macro (regional), medium (landscape), and micro (ecosystem) scales. Landscape metrics are defined at three levels or class, including 1. metrics at the patch level, which are defined for individual patches and consider the spatial and texture characteristics of the patch, 2. at the regional class, which are calculated for the total number of patches belonging to a specific class, and 3. at the landscape class, which are calculated for the entire area representing the characteristics of patch and region.

The main application of landscape ecology metrics is in environmental planning due to the quantification power of these metrics in landscape classification and zoning, as before using these metrics, ecologists had no solution for quantifying the relationships and interactions between plant (Flora) and animal species (Fauna) (Shabani et al., 2011).

The ability to quantitatively describe landscape structure is a precondition for studying functionality and alteration of landscape; to achieve this goal, various metrics have been derived from landscape ecology. For instance, according to the following models: 1- the Patch-Corridor-Matrix landscape model of Foreman (1995), and 2-the spatial framework model of Forman and Gerdon (1987) and Farina (1999), there are four essential patterns for sustainable landscape planning, including.

- Maintaining large patches of natural (native) vegetation, maintaining wide riparian corridors, preserving continuity for key species movement across large-scale patches, and maintaining heterogeneous natural patches within human-developed areas. Landscape metrics can provide a methodological framework for identifying and prioritizing habitat patches in urban ecosystems based on the structural and functional connectivity and continuity of the landscape (Soares et al. 2024).

- The material and methods of several articles were reviewed to study the factor of continuity to adopt the most applicable one. For example, in an article by Iranian authors, Kookhaie & Masnavi (2014), the principle of green space continuity, Aggregate with Outlier Principle (AWOP) was addressed to understand the effect of ecological infrastructure in landscape design on the quality of urban life. In a published research, they finally concluded that in the current century, to achieve sustainable urban development, the ecological design approach in urban landscape infrastructure is one of the most important urban design methods.

- Ramezani Mehrian and Faryadi (2014) used the principles of landscape ecology and existing theories and models (graph, minimum cost, and gravity) to analyze and shape the urban green space network and present an appropriate plan for developing the green space of Tehran's District 1 for achieving the aims including: increasing the connectivity, and proposing a plan for developing the green space of the region. Mahmoudzadeh and Masoudi (2019), in a study, addressed the increasing and improvement of the ecological continuity in the city of Tabriz to evaluate the integrity of green spaces by using the connectivity metrics such as COHESION and IIC (Integral Index Connectivity) to evaluate the continuity of green spaces in this city. Then, by using Linkage Mapper software, they simulated optimal corridors to create an ecological network for this city.

In the field of biodiversity conservation and landscape connectivity, Gorbani et al. (2021) used the IIC in their study to measure functional connectivity. They followed their study by creating a green space network using graph theory and the gravity model in the city of Maragheh, East Azerbaijan Province, Iran. The authors stated that using graph theory can simplify the complexity of the landscape towards protecting biodiversity. In the study by Hataminejad et al. (2023), land use mapping (2014 and 2021) was initially prepared using Landsat satellite images in ENVI 5. 3 software using a supervised image classification method in four classes: 1. built urban spaces, 2. Farm lands, 3. Garden Land, and 4. Wastelands; their results showed the ecological changes in the green space of the studied area over 7 years. Then, the land use changes of the region were prepared using ArcGIS, followed by the final step of analyzing data using Fragastas software. Masnavi and Mohseni Fard Naghani (2023) focused on improving the structure of the ecological network of green space in Municipality district 9, Tehran city, using landscape metrics for achieving a better quality of life and living, or natural? environment. Initially, by using satellite images and land use mapping of Tehran, the geographic data for the network mapping in the deteriorated urban fabric of District 9, Tehran municipality, were prepared. Then, the most important green space patches and their changes between 2002 and 2017 were evaluated by applying landscape metrics in the Fragstats 4.2.1 software. In a foreign paper, for analyzing a continuous ecological network, Kong et al. (2010) used six landscape metrics to identify networks, green patches, and potential corridors, and then introduced a continuous green space network for Jinan city using the gravity model and graph theory. In a similar article, Kupfer (2012) reviewed the use of landscape metrics and the relevant analysis process in the Fragstats software, and stated that these calculations can be an indicator for selecting patches and corridors as important connecting components in the ecological network. Lusting et al. (2015) analyzed four components of habitat and landscape using landscape metrics; they concluded that internal and external events in the landscape bring changes, separation, and a decrease in the size of landscape patches. Xio (2017) identified green space patches based on biotope maps and social needs of the city of Stockholm. By applying minimum cost analyses, the most optimal connection path between green space patches in the ecological network of this city was determined. In another related study by Zhang et al. (2019), by using Conefor and Fragstats software, the relationship between green patches in the city of Detroit was determined. In the second step, potential corridors were identified using the minimum cost model, and then an ecological network was created between the patches using graph theory; finally, the optimized ecological network for this city was selected using the elasticity model.

Chu et al. (2022), in a research study investigated the impacts of urban development on green space patches from 2000 to 2020 in Beijing, China; they predicted the landscape pattern using the Future Land Use Simulation Model Software (FLUS) for the year 2000 (Xiaoxia et al., 2022). The material and methods in 15 reviewed articles using calculated landscape metrics, ENVI, and Fragstats software were summarized in Table 2. As a result, it can be said that the lack of continuity of green space creates destructive effects in cities, as indicated in Fig. 2.

Materials and Methods

• Study area

Tehran, district 22, with an area of about 6,000 hectares, is an emerging urban region dependent on and affected by rapid urban developments and urbanization, which constitutes one-seventh of the area of the city and, as the largest neighborhood connected to Tehran, has shown increasing wide growth in recent decades. This type of growth and development has led to restrictions on the development of green space expansion and the reduction of urban open spaces, and in many cases has even led to the replacement of the artificial built areas. For example, many gardens, open green spaces, and public spaces have been replaced by residential and commercial structures during the change of use (Fig. 3).

• Research method and data

To accurately understand the temporal-spatial changes in Tehran's 22nd District, two qualitative and quantitative methods were used in this study. The qualitative method was used for addressing and evaluating the landscape's subjective components and indicators relevant to the residents of the region, including the ecological continuity description and the components for explaining the ecological continuity, to measure and verify quantitative components, and also the landscape metrics, which rely on remote sensing data, including Landsat 8 satellite measurements (Table 3). These images were selected due to some advantages, such as free access, multispectral images, a wide and integrated view, and repeated coverage of images over different courses of time. Following the capture of target images at the United States Geological Survey (USGS) for the study area, appropriate "landscape metrics" were selected based on the research conditions, and data were evaluated (Table 4). Moreover, according to the type of coverage in this area, an appropriate classification was considered, and landscape metrics were measured by applying the Fragstats v4. 2 programm that, followed by the final analysis based on the resulting data.

The landscape metrics were measured in a four-step process. In the first step, Landsat 8 satellite images were used to evaluate landscape elements from 2013 to 2020. To get the project aim, the Operational Land Imager (OLI) was used as a remote sensing instrument.

The relevant images (Figs. 4 & 5) were related to the relevant data in 2013 and 2023 captured from the EarthExplorer website (USGS).

In warm months with minimal cloud cover, it is followed by radiometric correction and delivering data as Digital Numbers (DN) to get radiance digital conversion in Collection 2 Level 1 in order to increase spatial and visual quality. In the second stage, the Quick Atmospheric Corrections (QUAC) method was applied to remove atmospheric effects that affect the signal measured by satellite sensors; in the third stage, for capturing a greater spatial resolution of the images, the panchromatic band

Table 2. The Methods for Measuring Landscape Metrics. Source: Authors.

Metric Tools	Published Article	Authors
Aggregate with Outlier Principle (AWOP)	1	Kokhaei & Matsnavi (2014)
Graph, minimum cost, gravity	1	Ramezani Mehrian & Faryadi (2014)
Integral Index of Connectivity (IIC)	2	Mahmoudzadeh & Masoudi (2019) /Ghorbani, et al. (2020)
Fragmentation Metrics: ENVI & Fragstate	5	Hataminejad, et al., (2023)/Masnavi & Naghani (2023) Kong et al. (2010) /Kupfer (2012) / Lusting et al. (2015)
GIS Raster Data	1	Mougiakou & Photis, (2014)
A Combination of methods	5	Zhang et al. (2019) /Chu et al., (2022) /Michael & et al. (2022)) /Xiaoxia et al., (2022)/ Xio (2017).

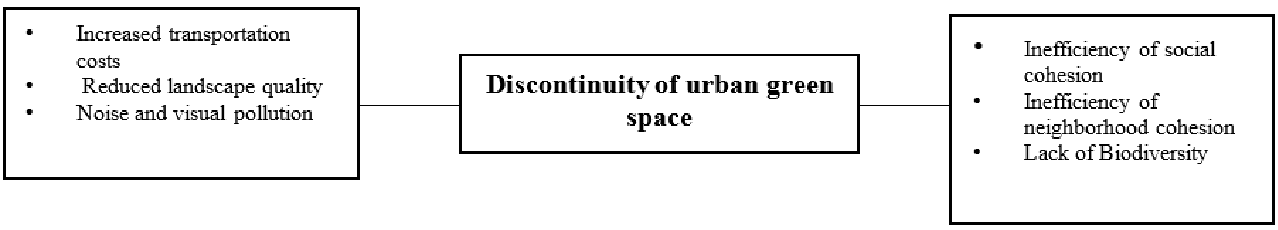

Fig 2. The Effects of Discontinuity in the Landscape of Urban Green Spaces. Source: Authors.


Fig. 3. Vegetation map of Tehran's 22nd district. Source: www.gahar_.ir_mataleb_15.02.98-9.

Table 3. The characteristics of the Landsat Satellite for capturing images. Source:Authors.

Source	Measure Tool	Satellite Type	Date
USGS	OLI/TIRS	Landsat 8	14/07/2013
USGS	OLI/TIRS	Landsat8	10/07/2023

Table 4. The Five Classification of the Land Cover in District 22, Tehran City. Source: Authors.

Land Use	Land Cover
environment devoid of vegetation	Bare Land (BL),
Vegetated area	Vegetation Cover (VC),
Lake	Water area
Access routes	Paved Road (PR)
Residential and industrial areas	Built-up Land (BUL)

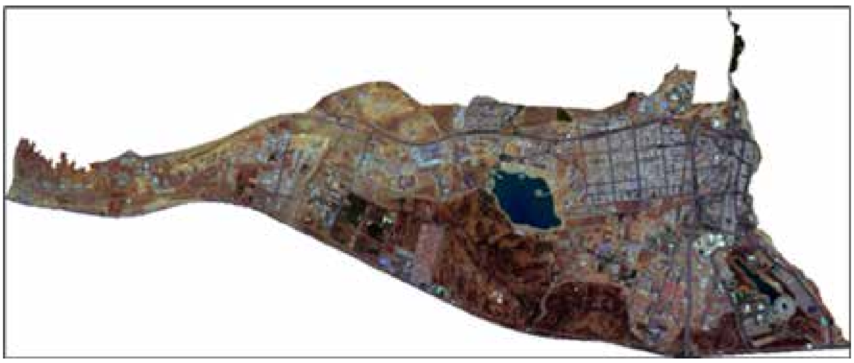
Fig. 4. Landsat 8 satellite images, 2013. Source: https://earthexplorer.usgs.gov.


Fig. 5. Landsat 8 satellite images, 2023. Source: https://earthexplorer.usgs.gov.

and the Gram-Schmidt Pan Sharpening were applied every two years. And finally, the processed images were cropped using the boundary of district 22. Subsequently, all processing steps were performed on the cropped image (Table 4). Then, the satellite images were processed using ENVI5.[3] remote sensing software. Considering the research aim and the existing land cover in the region, the images were classified and evaluated into five classes: 1. Bare Land (BL), 2. Vegetation Cover (VC), 3. Water area, 4. Paved Road (PR), and 5. Built-up Land (BUL) (Table 4). The capture images were analyzed using Fragstats 4. 2 software after classifying the data received from satellite, and the "total area/patch", "number of patches", "patch density", "class percentage", "largest patch index", "average patch area", and "adjacency and correlation index" were measured. The metrics of "number of patches", "patch density" and "Juxtaposition and correlation index" are "aggregation metrics" that provide information about the number and location of patches, while, the remaining metrics are "area and edge metrics" that provide us with information related to the area, the dominant area of the area, and the status of the floors. A more complete description of each metric is provided in Table 5. These metrics were calculated for each class both at the landscape scale and class scale for the years between 2013 and 2023 (Table 5).

Results

The final analysis was conducted at both the landscape and class levels based on the results acquired by processing through ENVI5. 3 maps. Based on the data presented at the Landscape level, the total area (TA) of the study area varies by approximately 5750 hectares. The number of patches (NP) increased from 1391 patches to 1687 patches between 2013 and 2023, indicating that patches are becoming smaller and the continuity of the landscape structure is being lost. Moreover, the patch density (PD) metric has increased from 24. 21 patches per hundred hectares to 29. 36 patches per hundred hectares, indicating patch fragmentation (Tables 6 To 8). The largest patch index (LPI), which is related to vegetated lands, has decreased by nearly 5% in every two years, which, in addition to indicating the fragmentation of patches, specifies heterogeneity in the landscape structure (Fig. 6). Another evidence of the fragmentation of patches and the loss of green continuity is the indicator of Mean patch area

Table .5. Description of metrics used in this research study. Source: Authors.

Adopted Metrics				
Range of Variation	**Level of Assessment**	**Unit of Measurement**	**Abbreviation**	**Metrics**
CA/TA>0	Class/Territory (Land) Scale	Hectares	CA/TA	Total Area/Class Area
TA: This metric shows the total area of the landscape, indicating that the other metrics were examined in this area. CA: This metric shows the total area of the class and all patches belonging to it.				
NP≥1	Class Level	_	NP	Number of Patches
At the class level, it indicates the fragmentation or integration of the landscape.				
PD> 0	Class Level	per 100 hectares	PD	Patch Density
It indicates the number of patches per hundred hectares; an increase in this metric means the landscape is becoming more fragmented.				
0<PLAND≤100	Class Level	Percentage (%)	PLAND	Percentage of Landscape of Class
It indicates what percentage of the total area is allocated to this class or scale, which can indicate which class has expanded or decreased.				
0<LPI≤100	Class Level	Percentage (%)	LPI	Largest Patch Index
It shows what percentage of the total area is covered by the largest patch of the target class. A low number is undesirable for natural patches, and a high number is undesirable for man-made patches.				
Area-MN≥0	Class Level	hectare	Area-MN	Mean of Patch Area
It represents the average area of patches in a class; this number should be large for natural patches and small for man-made patches.				
0<IJI≤100	Land Scale	Percentage (%)	IJI	Interspersion and Juxtaposition Index
It indicates the mixing of classes, so if a class is adjacent to only one other class, it approaches zero, and when it has equal proximity to all other classes, it is equal to 100.				

Table 6. Metric Variations at the Landscape Level. Source: Authors.

Variation	2023	2013	Unit of Measurement	Abbreviation	Metrics
-61.20	5745.3494	5744.6409	hectare	TA	Total Area
+136	1687	1391	_	NP	Number of Patches
+6.91	29.3629	24.2139	per 100 hectares	PD	Patch Density
-4.32	21.3362	21.3866	Percentage (%)	LPI	Patch Density
-2	3.4057	4.1299	hectare	AREA-MN	Mean of Patch Area
-6.96	76.6218	75.3721	Percentage (%)	IJI	Correlation and Juxtaposition Index

Table 7. Metrics at the class scale, 2013. Source: Authors.

IJI	AREA_MN	LPI	PD	NP	PLAND	CA	Classes	CLASS
76.4833	6.6144	21.3362	5.6045	322	37.0705	2129.8294	Vegetation Cover (VC)	
79.9103	4.0913	3.4792	7.6932	442	26.8659	1808.3357	Built-up Land (BUL)	
71.4197	2.4763	4.7171	7.3277	421	27.9651	1606.4943	Bare Land (BL)	
76.6092	1.2465	3.3806	8.6853	499	18.1452	319.811	Paved Road (PR)	
78.1545	47.5598	2.1535	0.0522	3	2.4834	142.6794	Water area	

Table 8. Metrics at the class scale, 2023. Source: Authors.

IJI	AREA_MN	LPI	PD	NP	PLAND	CA	Class	CLASS
71.4278	7.9776	20.3259	4.6478	267	37.0781	2130.0065	Vegetation Cover (VC)	
80.0676	3.2837	4.5712	8.1815	470	31.4748	1543.3469	Built-up Land	
71.4727	6.75	21.3866	4.143	238	5.5671	1042.5076	Bare Land (BL)	
76.0948	0.7744	0.5874	7.1893	413	10.8261	621.9973	Paved Road (PR)	
98.316	48.3274	2.1476	0.0522	3	2.5238	144.9821	Water area	

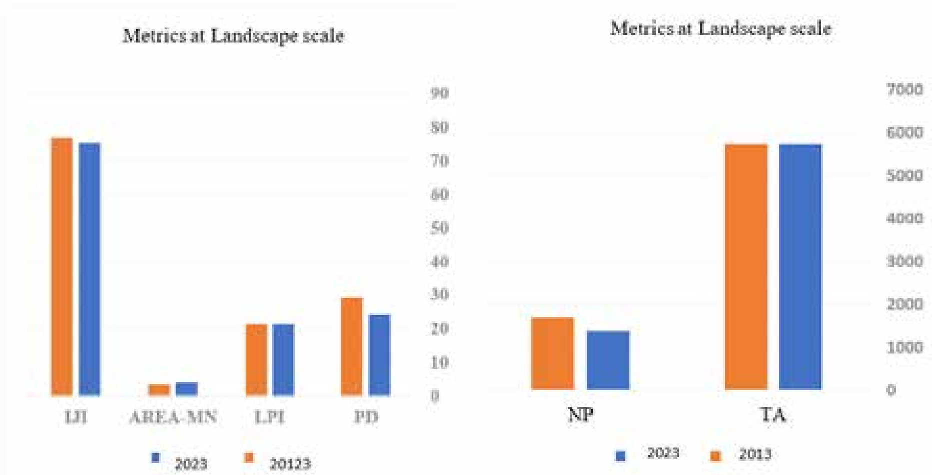

Fig. 6. The Landscape Metrics (in hectares) for the years 2013 & 2023 in District 22, Tehran. Source: Authors.

(Area_MN), which has decreased from 4. 1 hectares in 2013 to 3. 4 hectares in 2023.

The proximity/juxtaposition and Interspersion-Juxtaposition Index (IJI) at the landscape level has increased by approximately 1%, indicating that the proximity of different patches to each other has increased, and the mixing of patches has increased at the landscape scale, as the first diagram shows.

By analyzing the data at the class level, it can be concluded that the land use area at the class scale, Class Area (CA), in the vegetation and watershed classes has not changed significantly. An increase is observed in the built-road and man-made classes. However, barren lands have decreased according to the data. The increase in built-up lands and roads, along with the decrease in barren lands, indicates a change in urban structure by humans. The Percentage of Landscape (PLAND) class shows that barren lands decreased by 9 percent, while lands with vegetation and water bodies remained almost constant, while roads increased by about 5 percent, as shown in the second diagram (Fig. 7).

As the diagram shows, the number of patches (NP) has shown a decrease since 2013 for the vegetation, wasteland, and road classes, while an increase has been found for the built-uplands (man-made class) and a constant value for the water area. The decrease in the number of patches is due to the expansion of this class and the continuity The analysis of patch density (PD) shows the same metric variations as the number of patches (Fig. 8).
The largest patch index (LPI) in 2013 included vegetation, Bare Land, man- made/ built-up land, paved road, and water area, respectively. However, in 2023, this order has been changed, with bareland having the highest index, indicating a decrease in fragmentation of this class, followed by vegetation, man-made areas, paved roads, and water areas. LPI in the vegetation class was very small; however, the increase of this index for bare lands was to the point where in 2023 the largest index was allocated to this class, indicating a decrease in vegetation cover and an increase in water area (Fig. 9). During this time, the Mean patch area (Area_MN) for the 'water area' shows the highest number in both years, 2013 and 2023. The largest water area is related to the artificial lake of Chitgar. Considering the area of 250 hectares of this patch and its significant difference from the vegetation land around and the relevant metrics, it is necessary to consider appropriate proceedings in urban planning to strengthen this area. For this metric, in 2013, the classes included the following: vegetation, man-made lands, bare lands, and paved roads; while in 2023, this order has changed, as after water area, the other classes, including vegetation, bare lands, man-made area, and roads, were placed. Interspersion-Juxtaposition Index (IJI) for vegetation showed decreased proximity, while for man-made lands and water areas represented increased proximity; this index for bare lands and paved roads showed a very slight increase and decrease, respectively.
Considering the metric number of the water area, it is clear that this class has more proximity to all other classes than other areas from 2013 to 2023, which indicates greater fragmentation and merging of the landscape. Moreover,

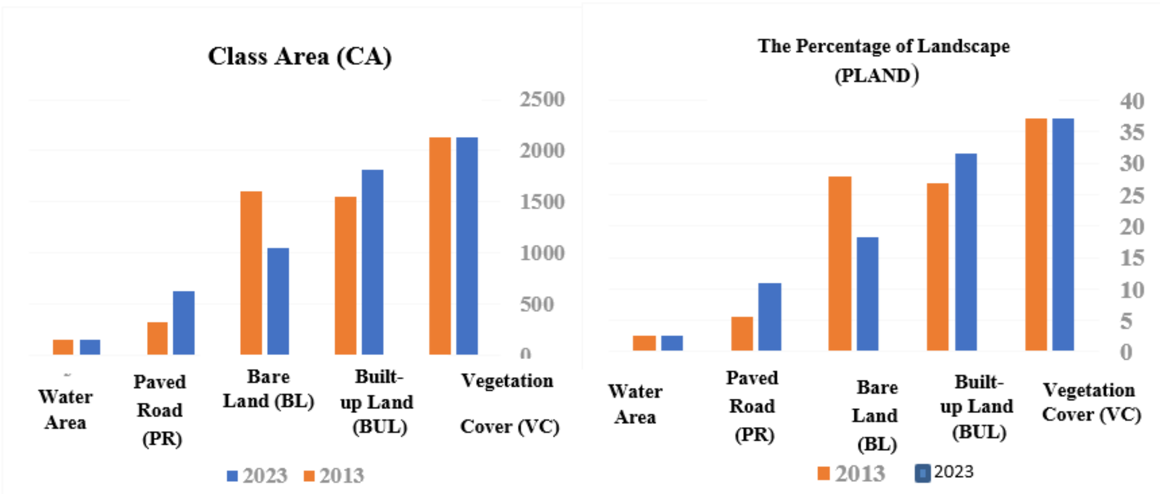

Fig. 7. Class Area (CA) and The Percentage of Landscape (PLAND) in 2013 & 2023; District 22, Tehran. Source: Authors.

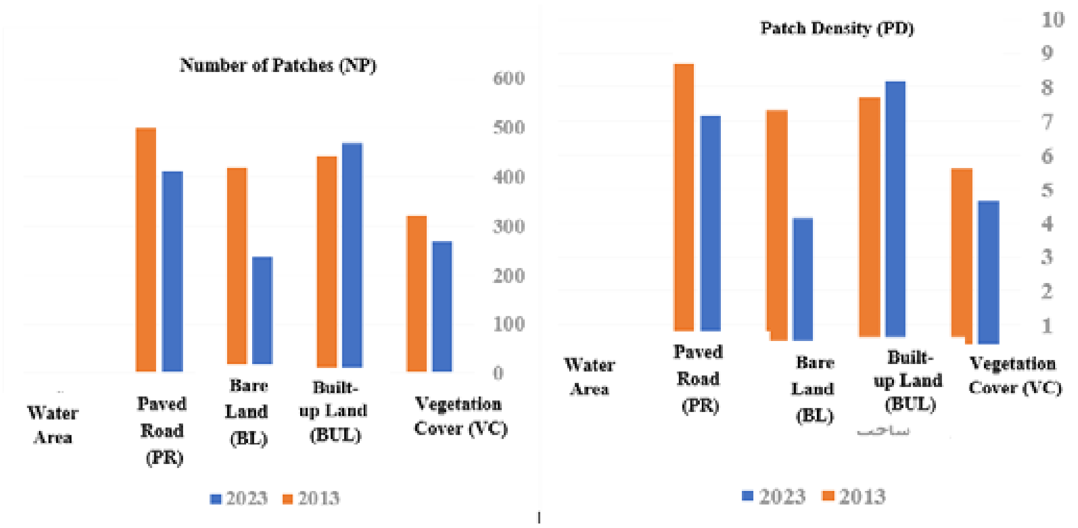

Fig 8. The Patch of Density (PD) and Number of Patches (NP) in 2013 & 2023; District 22, Tehran. Source: Authors.

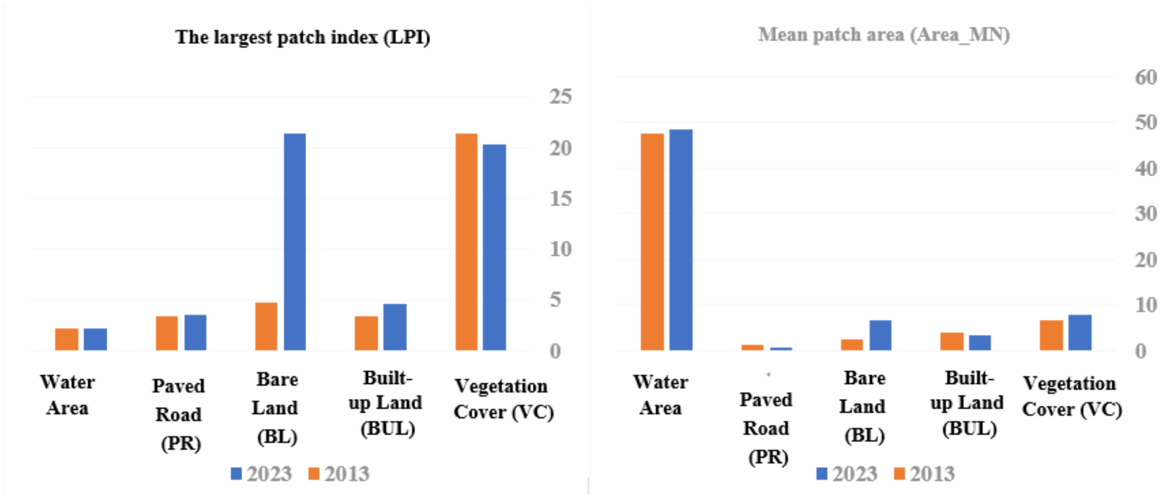

Fig 9. The Largest Patch Index (LPI) and Mean Patch Area (Area_MN) Metrics in 2013 & 2023; District 22, Tehran. Source: Authors.

the measurements of this metric for other classes show that the proximity index for all other classes is greater than 70, which indicates a high merging level of different zones with each other (Fig. 10).

Interpretation of this metric, in relevant with other metrics, suggests that over time, factors influencing the process of changing the structure of green space have resulted in fragmentation and disconnection of large patches. This transformation could indicate a decrease in continuity between green patches and, thereby, a decrease in the performance and ecological sustainability of green lands in the study area.

Moreover, comparison and analysis of the metric`s density of the 'edges of green patches relative to built-up urban areas' indicates the progress of destruction in the regional landscape.

Conclusion and Recommendations

The urban landscape is not a constant portrait observed by a viewer from a specific point; it is a concept that is perceived sequentially. By taking any step of a pedestrian forward, part of the space behind him/her will disappear, and he /she is confronted with the new scenes forward.

Using a compound approach to be enough applicable to evaluate the pattern of urban expansion and its effects on the landscape, relatively quickly and accurately, by applying the history of land use data, is of great importance to urban and landscape planners.

Monitoring and predicting structural changes in the landscape due to urban expansion over time using specialized tools, including satellite imagery, spatial modeling in a geographic information system environment, and landscape metrics, is a suitable approach to investigate the environmental impacts of urban development.

From the ecological point of view, maintaining large green spaces and connecting them leads to greater landscape sustainability. The more connected and integrated the urban green space networks in an area, the greater the ecological sustainability.

In District 22 of Tehran Municipality, by constructing urban lands during the course of this study, the number of large patches of green space, with high ecological value, has been replaced by smaller patches with lower value, as the connection between green space patches has also been detached. According to the research study, the landscape of District 22 of Tehran is losing the continuity of green space and decreasing the quality of the landscape due to increased construction. However, examining landscape metrics in the vegetation class, given the constant patch area and percentage of this class, along with the decrease in the number and density of patches, suggests that despite the increase in construction, a successful effort has been made to preserve vegetated lands in recent years.

The research findings, besides revealing the changes that have occurred in this region, have provided a structure for future ecological management strategies. The integration of ecological networks into land-use planning is essential to maintain biodiversity and ecosystem profits in confrontation with the ongoing environmental challenges.

Finally, similar research studies are recommended on other regions of Tehran city and a comprehensive research for the whole districts of Tehran metropolitan area in order to make a more livable and natural green environment spaces for residents enriched with animal and plant species in an urban ecosystem.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

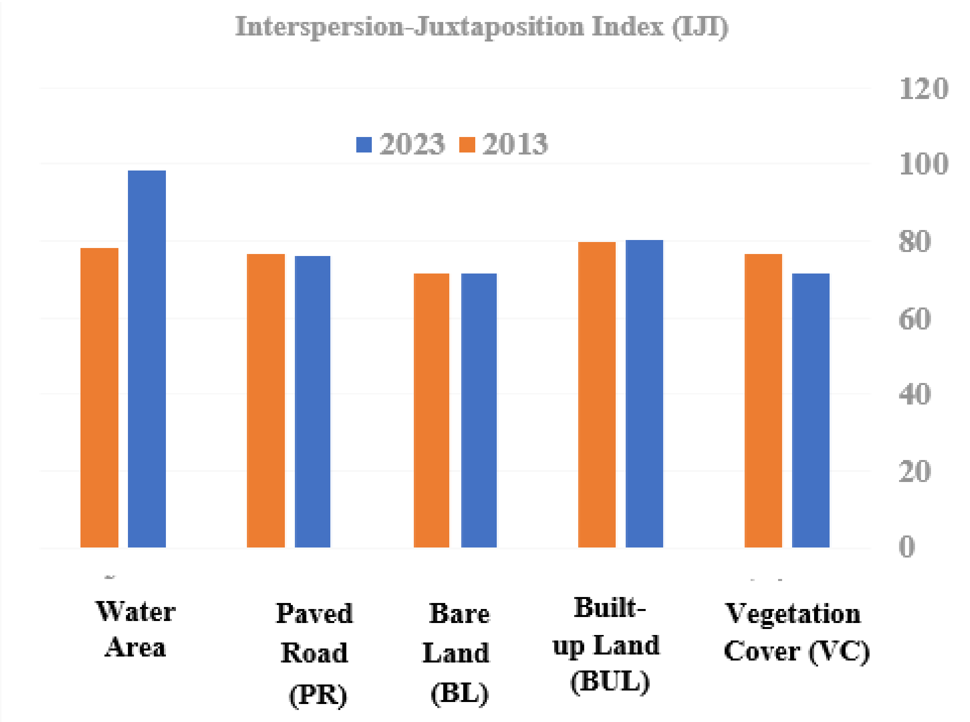

Fig. 10. The Interspersion-Juxtaposition Index (IJI) Metric (in hectares) in 2013 & 2023; District 22, Tehran. Source: Authors.

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