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The cover image is a photo of impacts on transport infrastructure of typhoon Hagibis in Japan (October, 2019)

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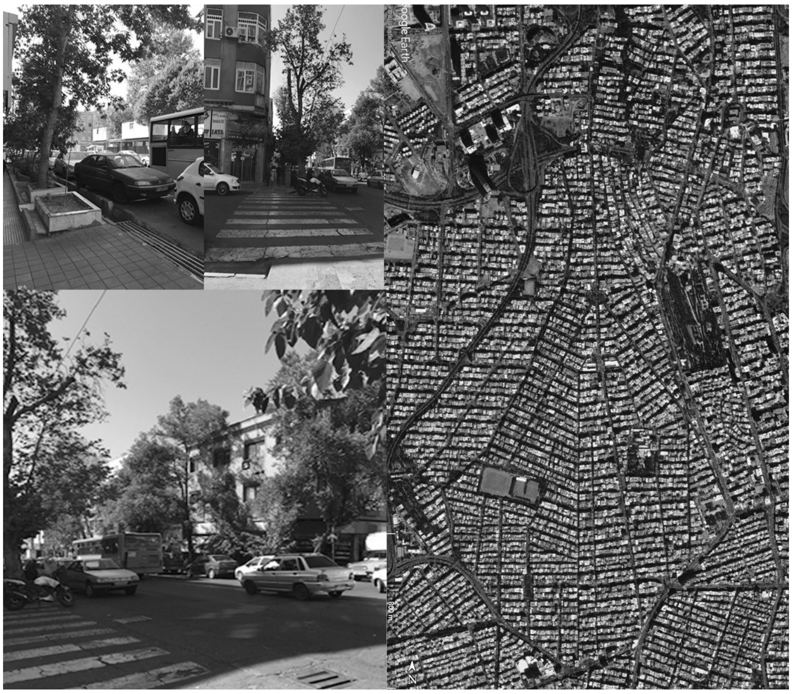

DEFINING URBAN GREEN INFRASTRUCTURE ROLE IN ANALYSIS OF CLIMATE RESILIENCE IN CITIES BASED ON LANDSCAPE ECOLOGY PRINCIPLES

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ABSTRACT

Climate change is a globally widespread phenomenon. Urban development and climate change are closely interrelated; cities are exposed to the risk of climate change and as a result, are very vulnerable. In recent years, to face the challenges caused by the climate change, the concepts of, urban ecological resilience, specifically, climate resilience have been introduced. Climate resilience, is a type of urban ecological resilience, which is defined as the urban resilience to climate change.
Urban green infrastructure has an established role as one of the strategies for adapting to climate change and for developing and promoting climate resilience in cities. Given the theoretical gap existing in this field, this question arises: "How and based on which features of the green infrastructure can we assess and analyze climate resilience in a city?" To answer this question, the landscape ecology principles and relationship between them and green infrastructure in cities were studied. The relationship was developed in the Yousef Abad neighborhood of Tehran and was qualitatively tested using the aerial images, field surveys and preparation of basic and analytical GIS maps. Finally, the 'effective qualities in assessing the climate resilience in cities using the urban green infrastructures based on landscape ecology' were obtained.

KEYWORDS:
Climate change; Urban climate resilience; Urban Green Infrastructures; Landscape Ecology; Yousef Abad Neighborhood in Tehran

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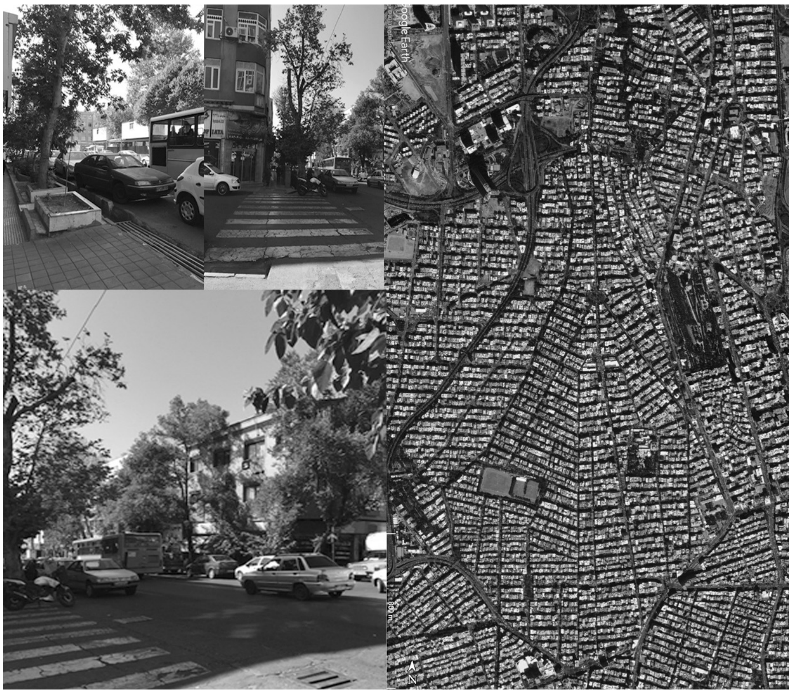

基于景观生态学原理来定义城市绿色基础设施在城市气候弹性度分析中的作用

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摘要

气候变化是一个全球性的现象。城市发展与气候变化密切相关；城市面临着气候变化的风险，因此非常脆弱。近年来，为了应对气候变化挑战，引入了城市生态弹性度的概念，特别是气候弹性度。气候弹性度是城市生态弹性度的一种，被定义为城市在气候变化面前所表现出的弹性。
作为适应气候变化以及发展和促进城市气候弹性度的战略之一，城市绿色基础设施已经确立了其作用。鉴于该领域存在的理论差距，进而引发了这一问题：“我们应该如何以及基于绿色基础设施的哪些功能来评估和分析城市的气候弹性度？”为了回答这一问题，我们对景观生态学原理及其与城市绿色基础设施之间的关系进行了研究。这种关系是在德黑兰的优素福阿巴德街区发展起来的，并通过航拍图像、实地调查以及编制基本和分析 GIS 地图进行了定性测试。最后，得出了“基于景观生态学使用城市绿色基础设施来对城市气候弹性度进行评价的有效质量”。

关键词：
气候变化；城市气候弹性度；城市绿色基础设施；景观生态，德黑兰的优素福阿巴德街区

1 INTRODUCTION

Cities all over the world face a wide range of hazards that are affected by the factors such as increased urban population and climate change (IPCC, 2008). Urban development and climate change are closely related. Cities are exposed to the risk of climate change and are very vulnerable (Mishra, 2017).

In this respect, in recent years, urban resilience concept has been developed to reduce these negative effects. Resilience is the ability of a system to absorb the disturbances while maintaining the basic structure in the same way and the functional methods, the capacity for self-organization and the capacity to adapt to stress and change (IPCC, 2008). Adaption to climate change focuses on reducing vulnerability to these changes (Leichenko, 2011). Resilience has different dimensions, among which 'climate resilience' as a type of urban ecological resilience is considered in this study (Childers & Cadenasso, 2015), which includes adaptation to and mitigation of the risks and adverse effects of climate change (Asian Development Bank, 2014).

Urban green infrastructure has various vital functions, including the environmental, social, etc., according to research, it is effective in reducing the impacts of climate change in cities and enhancing climate resilience (Byrne et al., 2015).

Reviewing the literature on urban green infrastructure related to its role in creating urban (climate) resilience, characteristics of green infrastructure and the amount of effectiveness based on the development, analysis and evaluation of urban resilience to climate change have not been properly addressed so far. In general, no exact factors have been provided to assess this kind of resilience. It seems that these characteristics can be used as important factors for assessing the quality of climate resilience.

To achieve this goal, the relationship between landscape ecology and its principles is useful for analyzing the resilience potential of green urban infrastructure. Consequently, this relationship will be scrutinized in this paper in a theoretical manner. Then, the principles and results obtained from this study, will be implemented in Yousef Abad neighborhood in Tehran, Iran. Tehran is a city with many problems due to climate change, such as air pollution, drought, increased temperature and lack of water resources. By conducting field surveys, use of aerial images of area of study and preparation of basic maps and analysis using GIS software, this research provides a proposed model and framework based on its question for using the existing green infrastructure in a city to assess quality of climate resilience based on principles of landscape ecology. In the following, the theoretical framework required for this research is introduced.

2 TERMINOLOGY

2.1 CLIMATE CHANGE AND URBAN CLIMATE RESILIENCE

Today, direct and indirect effects of climate change on the low-income and middle-income residents can be seen in the countries that have had the least impact on global warming and climate change. Certainly, the low-income class will be mostly effected from climate change (Asian Development Bank, 2014). Urbanization and climate change have a negative impact on quality of life, economic situation and social stability. The areas with the concentration of population, industries and infrastructure (green–grey), are mostly influenced by climate change. Some urban areas are also more vulnerable to greater impacts of climate change including high temperatures, rising sea levels, precipitation fluctuations due to their geographical situation. Urban dynamic intensifies the effects of climate, the rapid growth of cities will replace the vegetation with hard building surfaces (IPCC, 2008), as a result, the precipitation is reduced and temperature rises. This is what will be discussed more in the case study section of this research. Reducing the impacts of climate changes is related to these five key factors: 1) City form, 2) Construction, 3) Artificial environment, 4) Urban infrastructure, and 5) Transportation and production of carbon (Connell et al., 2017). This research is focused on urban infrastructures, specifically 'green urban infrastructures'.

Concept of urban resilience has been proposed in recent years to reduce and adapt to these changes. In this study, 'climate resilience', a type of urban ecological resilience, will be discussed. To accurately define the concept of climate resilience, it is necessary to first provide an exact definition of the concept of resilience: resilience refers to 'return to the past' and even 'the ability to easily and immediately return to the previous state', meaning the "elasticity" or flexibility (Adhya, 2010). According to the large scientific literature on the resilience concept and namely on its importance for coping with uncertainty, resilience can be a useful concept for driving strategies addressed to urban adaptation in face of climate change, mainly due to these aspects: resilience is conceived as a conceptual approach to deal with uncertainty and future change with respect to traditional approaches mainly focused on system's control; resilience represents a premise for a proactive response to disasters as it embodies the concept of adaptive and learning capacity, which is typical of living systems; resilience gives room to the emergence of new configurations of the system (even more desirable than the previous ones) after a disturbance, as a result of the self-organization capacity that is typical of complex systems, (Galderisi & Ferrara,2012).

Folke (2006) claims that,' Resilience deals with complex adaptive system dynamics and true uncertainty and how to learn to live with change and make use of it. In popular terms, resilience is having the capacity to persist in the face of change, to continue to develop with ever changing environments. Resilience thinking is about how periods of gradual changes interact with abrupt changes, and the capacity of people, communities, societies, cultures to adapt or even transform into new development pathways in the face of dynamic change. It is about how to navigate the journey in relation to diverse pathways, and thresholds and tipping points between them.

Types of resilience include: 1) urban ecological resilience, 2) urban-regional-economic resilience; 3) resilience to reduce urban hazards and accidents; and 4) resilience enhancement through urban governance (Childers & Cadenasso, 2015).

Urban ecological resilience refers to the capacity of ecological systems to absorb the disturbances and also to maintain the feedbacks, processes, and structures necessary and inherent to the system. In other words, it is the severity of the disturbance the system can absorb before the structure of the systems is transformed into a different structure by changing the variables and processes that control its behavior. Climate resilience, is a type of urban ecological resilience (Schipper, 2007). According to the definition of ecological resilience and taking the concept of climate change into account, climate resilience includes: the capacity of an independent unit or a group or organization to respond to climate change in a dynamic and effective manner, while still continuing to daily activities in an acceptable level. This feature includes the resistance to change, recovery after the shock, and reorganization to prevent the destruction of the system that is the city, here and for continued life (Dayland & Brown, 2012). A definition of urban climate resilience is also provided by the Environmental Protection Agency (United States Environmental Protection Agency, EPA, 2017): it is a city's ability to reduce exposure and sensitivity to, and recover and learn from, gradual climatic changes or extreme climate events. This ability comes from a city's risk reduction and response capacity, and includes retaining or improving physical, social, institutional, environmental, and governance structures within a city,(Errigo,2018). In general, climate resilience, is urban resilience to climate change (Fig. 1).

The factors contributing to climate change include infrastructures, institutions, ecosystems, and capabilities of organizations and authorities (Miller et al., 2009) (Fig. 2).

To sum up, infrastructure is among the factors affecting the development and promotion of climate resilience in cities, urban green infrastructure (UGI) are in focus here which will be further discussed.

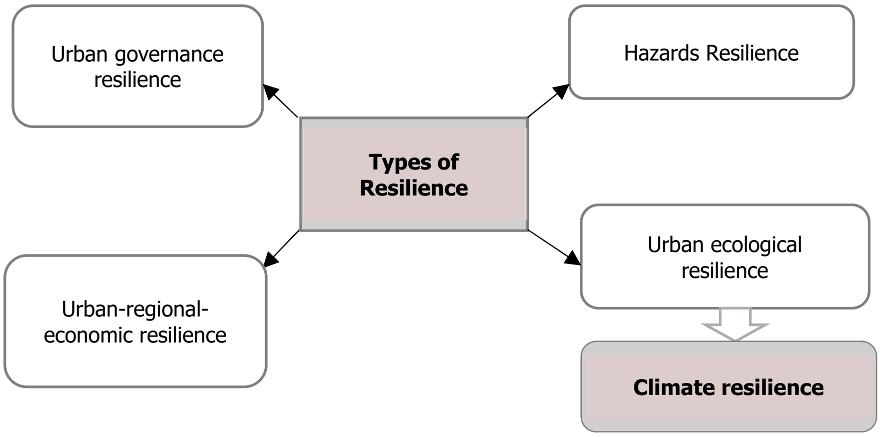

Fig.1 Relationship between climate resilience and other types of resilience

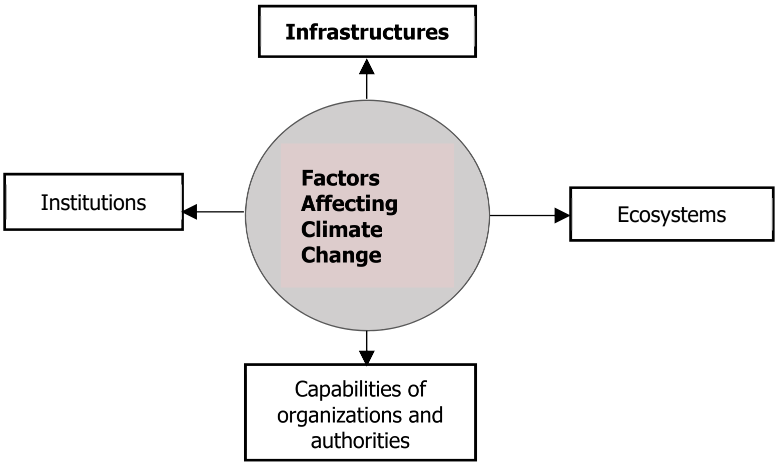

Fig.2 Factors affecting climate change

2.2 URBAN GREEN INFRASTRUCTURES AND THEIR ROLE ON INTEGRATING URBAN CLIMATE RESILIENCE

The influential factors in developing and enhancing climate resilience include various types of infrastructures such as green infrastructures. They are considered as one of the most important urban elements. The term infrastructure as a park and green space was first used in 1996 to define public parks as a subcategory of urban infrastructure. Green Infrastructure (GI) is defined as an ecosystem or a network of ecosystems with specific parts, needs, functions and services, an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations (Bianoci et al., 2018). Green infrastructures include a related network of green spaces that are strategically managed, have many functions, and are useful in ecological, social and economic terms (Pataki et al., 2011). Urban green infrastructure is a kind of ecological social system which results from the interactions of various elements, especially human beings. On the other hand, the components of green urban infrastructure can be considered as a combination of open and closed spaces and a mixture of natural plant habitats, which are of great ecologic, social and economic significance. As a result, the proper design in these spaces can have a profound effect on everyday life, also resilient design is considered one of the most appropriate principles for the design of such spaces (Oliver, 2014). In general, GI includes green roofs, permeable green surfaces, green paths and streets, urban forests, public parks, neighborhood gardens, and urban wetlands, (Demuzere et al., 2014).

Urban green infrastructure (UGI), is one of the most important 'strategies for adaptation to climate change'. Adaptability has been defined as "the capacity of actors in a system to influence resilience" (Derzken, 2017) and is about adapting within critical social-ecological thresholds. Adaptability is central to persistence. It helps turn changes and surprises into opportunities and, hence, is an important part of social-ecological resilience (Berkes et al., 2016).

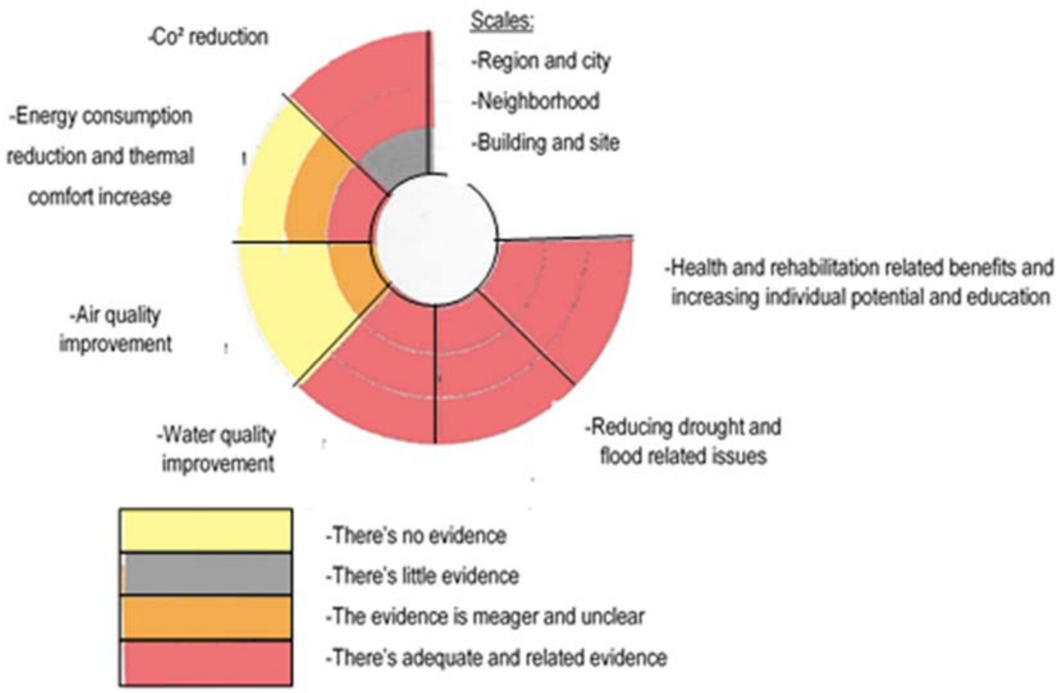

Fig.3 The link between the effects of urban green infrastructure and their impacton climate change reduction and adaptation in three scales and evidence-based

Green infrastructure plays a significant action to mitigate the effects of climate change in the urban environment, promoting adaptation strategies of cities (Salata & Yiannakou, 2016).GI can enhance the cities' climate and reduce the impacts of climate change in future (Foster et al., 2011). It can play an important role for the reduction of emissions, prevention of hydro-geological collapse, soil protection, improvement of air quality and conservation of genetic resources potentially better suited to cope with extreme weather and socio-economic conditions (Bianoci et al., 2018). It also reduces the effects of heat islands and floods in cities as well (Byrne et al., 2015). The effects of green structures on reducing the climate change impacts and increasing the resilience in cities can be divided into several categories: 1) Physical effects; 2) Increased thermal comfort and reduced energy consumption; 3) Reduced negative effects of floods, increased water quality and reduced drought; 4) Impact on air quality; 5) Positive psychological and social effects; 6) Impact on health, social and individual activities, education (Demuzere et al., 2014). In Fig. 3, the impact of urban green infrastructure on climate resilience and adaptation to climate change are displayed. The effects of UGI as an important strategy for adaptation to climate change on: reducing drought, extreme heat, precipitation reduction and air pollution are the main focus of this research, therefore they will be discussed more in the next section.

2.3 CLIMATE CHANGE ADAPTATION STRATEGIC PRINCIPLES

Using UGI as an adaptive strategy is mostly applicable in areas dealing with extreme heat, drought, precipitation reduction, air pollution and water shortage. These conditions can be generalizable to the current state of climate change in many countries around the globe with the same problems due to climate change. Different countries face different types of climate change challenges according to their location and climate conditions, population and natural resources.

As Gill (2007) states, adaptation strategies to climate change, regarding urban green infrastructure, are categorized in three general strategic principles, (Fig. 4): A) *Preservation and Enhancement of Existing Vegetation:* One of the important strategies for reducing the temperature in the warm seasons is preservation and maintenance of existing vegetation whether in private gardens, public green spaces or in green spaces on the streets. There's a fact that in many urban areas, hard and built infrastructure already exist, and it is impossible to change their land use and replace them with large green spaces. In these circumstances, green infrastructure must be added to the environment creatively, using special methods.

Among these methods, the use of green roofs, green facades, planting of rows of trees along the streets and railroads and turning the streets into green corridors can be referred to. Priority should be given to areas where people's vulnerability to climate change is high. Areas with higher poverty, extreme heat, high population and etc., are the most vulnerable.

B) *Using Climate-tolerant Plants:* Another strategy is the use of drought tolerant plants. It goes without saying that one of the negative effects of climate change is causing droughts. Under such conditions, the use of plants with less water requirements and less susceptibility to climatic conditions is effective. Some types of plants are very resistant to specific climatic conditions, including drought. The use of trees is very suitable in such conditions. These plants continue to shade and evaporate under severe climatic conditions. To plant such trees on the streets, it should be noted that the roots of them have good space and conditions. In addition, their placement must be selected correctly. Conditions of irrigation are also very effective and it must be ensured that enough water will reach these trees. Water for irrigation of plants under drought conditions can be provided by reuse of gray or underground waters in the suburbs or by storing water obtained from flood and precipitation (Gill et al., 2007).

C) *Use of Science of Landscape Ecology in finding Proper Locations for Green infrastructures in New Urban Projects and also in quantitative analysis of the UGI resilience to climate change:* To deal with climate change, the location of the green infrastructures is very important. The last strategy presented here, is the main focus of this research which will be discussed in the following section. To complete the strategic principles mentioned above. Based on the theoretical framework presented previously, some key facts can be discussed in the following section.

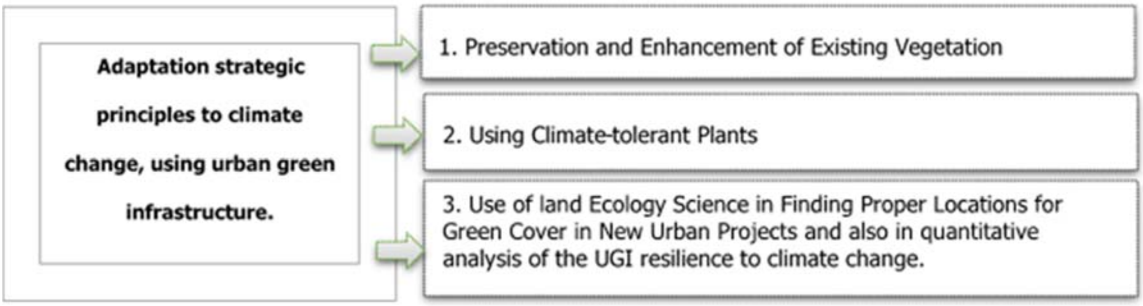

Fig.4 A Framework for Climate Adaption Strategic Principles Using Urban Green Infrastructure to Improve Climate Resilience in cities facing drought, extreme heat, precipitation reduction and water shortage

2.4 RELATIONSHIP BETWEEN LANDSCAPE ECOLOGY AND URBAN GREEN INFRASTRUCTURE AND RESILIENCE TO CLIMATE CHANGE

During the 1980s, advances in the accessibility of computing, remotely sensed satellite and aerial imagery, development of geographic information systems (GIS, ARC/INFO was first released in 1982), and spatial statistical methods (Fortin & Dale 2005), enabled ecologists to observe and analyze spatial heterogeneity ranging from local habitats to entire continents. Landscape ecology, then, involves the study of these landscape patterns, the interactions among the elements of this pattern, and how these patterns and interactions change over time (DucUy & Nakagoshi, 2008).It is best distinguished by its focus on: 1) spatial heterogeneity, 2) broader spatial extents than those traditionally studied in ecology, and 3) the role of humans in creating and affecting landscape patterns and process (Forman, 1995) and by spatial heterogeneity and pattern: how to characterize it, where it comes from, how it changes through time, why it matters, and how humans manage it (Forman & Godron, 1986).

According to Forman and Godron (1986), components of green infrastructure can be classified into three elements: *patch, corridor and matrix***.** A patch is an area of habitat differing from its surroundings, often the smallest ecologically distinct landscape feature in a landscape mapping and classification system .The characteristics of patches are important in landscape ecology, (e.g., the size, shape, or perimeter to area ratio of individual patches). The matrix is the majority of the surrounding landscape (i.e., not the patches); the large proportion of the landscape classified as matrix may have profound influences on the ecological processes in the landscape. Corridors are narrow patches that may act as links or barriers in a landscape. Beyond the image of narrow patches, corridors are functionally important landscape structures influencing dispersal of plants and animals in the landscape (Haddad et al. 2003). Ecologists have been particularly interested in how the spatial distribution of elements affects ecological processes, (McGarigal, 2001).

The development and dynamics of spatial heterogeneity in landscapes is a central theme of ecological studies, especially the effects of conversion of natural ecosystems into human dominated systems such as UGI or urban land use. As natural habitat (UGI) is altered in a landscape, (or city) both the composition and the configuration (spatial pattern of patches) change. This conversion is called fragmentation (in cities, green patches are fragmented during time because of city growth). Evidence is mounting that change in composition has a dominant effect on composition of the biota, whereas variation in configuration has a lesser effect, except at very low proportion of patch composition in the landscape (Fahrig, 1997). This interest has led to the emergence of a dynamic mosaic paradigm (Haddad et al., 2003), which complements the patch-corridor-matrix paradigm. Landscape concepts regarding loss and fragmentation of vegetation cover around the world have become fundamental to understanding the carbon cycle, and predicting the consequences of global climate change (Houghton, 1995).

The patch-corridor-matrix paradigm is what will be used later, to analyze the existing UGI, as a climate change mitigation strategy in the area of study, in this research. To deal with climate change, spatial analysis of components of landscape ecology is necessary, the location, of green cover is very important, whether monitored during a length of time or at the exact time of the analysis.

Each of these elements has the following benefits on climate change effects: Corridors are effective in storing the water from flooding and controlling flood flow, patches are mostly effective in restoring the rainwater and preventing it from flooding. The cooling of space through evaporation is further done by patches than matrixes, and the appropriate micro-climates are also created in the patches, Matrixes are more effective in treating the rainwater than the patches (Gill et al., 2007).

When the green spaces are greater than one hectare, they create a good microclimate. Shading occurs in the patches and matrixes, which leads to cooling of residential areas (Forman, 1995).Therefore green patches and their status are important in this study. Generally, green space is effective in reducing the rate and amount of surface runoff in sandy soils. The creation of protected areas on such soils can be a good strategy for the areas with such soil types (Gill et al., 2007).

	CORRIDOR	PATCH	MATRIX
Retention of water from flood	⋆⋆⋆	⋆⋆	⋆
Water Treatment property	⋆	⋆⋆	⋆⋆⋆
Cooling through evaporation	⋆	⋆⋆⋆	⋆⋆
Shading	⋆	⋆⋆	⋆⋆⋆

⋆ Mark shows the effect of corridor, patch and matrix on various kinds of climate changes.

Tab.1 Typology and influence of urban green infrastructure on adaptation to climate change from landscape ecology point of view (Gill et al., 2007)

Imaging and mapping technology naturally promoted a patch-corridor-matrix approach to landscape ecology. Examining the map or aerial image of an area helps to define important vocabulary, (Clark, 2010). In this article the main purpose is to use the 'patch-corridor-Matrix heterogeneity model', to analyze and read, the quality of existing urban green infrastructure in a city based on its climate resilience potentials. By using this approach, and analyzing the heterogeneity of the components of landscape ecology, the greatest function and relationship of landscape ecology with urban green infrastructure will appear and that is to locate, suggested green cover in new urban projects by reaching solutions to guide green patches and corridors to the their utter heterogeneity and to lesser the fragmentations caused by urbanity during the years. The above cases can be used both for new urban areas and projects and also, to preserve and enhance the vegetation available in an area. As Galderisi (2014) states, for using UGI to face climate change impacts: existing green spaces in cities must be preserved and looked after, authorities and decision makers must provide the city with more green and blue spaces, and green continuous networks (corridors) must be created in cities.

In Tab. 1, types (typology) of green infrastructure based on landscape ecology's classification, displays how elements of landscape ecology, can be effective in integrating resilience to climate change (Gill et al., 2007; Shirgir et al., 2019).

In addition to the type of green infrastructure, the landscape ecology states that the position and location of the patches, corridors and matrixes are effective in promoting the resilience (Gill et al., 2007). Also, the size of these factors can affect climate resilience. This way, the wider the green patches, the more resilient they are, and the more extended and connected the natural and artificial corridors, the more ensured the resilience. These measures and measurable data can play an important role in assessing the climate resilience. By spatially analyzing a city and measuring the number of green patches, corridors and matrixes of the city, their existence or absence, how they are placed beside each other, their connection and fragmentation, their size, health and suitability of existing vegetation in the city, an accurate spatial-qualitative (if more studied into details even a proper quantitate method) assessment of resilience in cities can be provided.

By conducting such analysis, some suggestions and principles can be presented in the next step for improving the current situation and strengthening green spaces of any type in cities. In this respect, the principles and method of assessing and analyzing the situation of urban green infrastructure are depicted based on the landscape ecology (Fig. 5).

According to this figure and using the principles derived from the relationship between the landscape ecology and urban green infrastructure and climate resilience, correct location for a new, strengthened green infrastructure can be found using the patch, corridor and matrix theories (correct location of proposed green infrastructure).

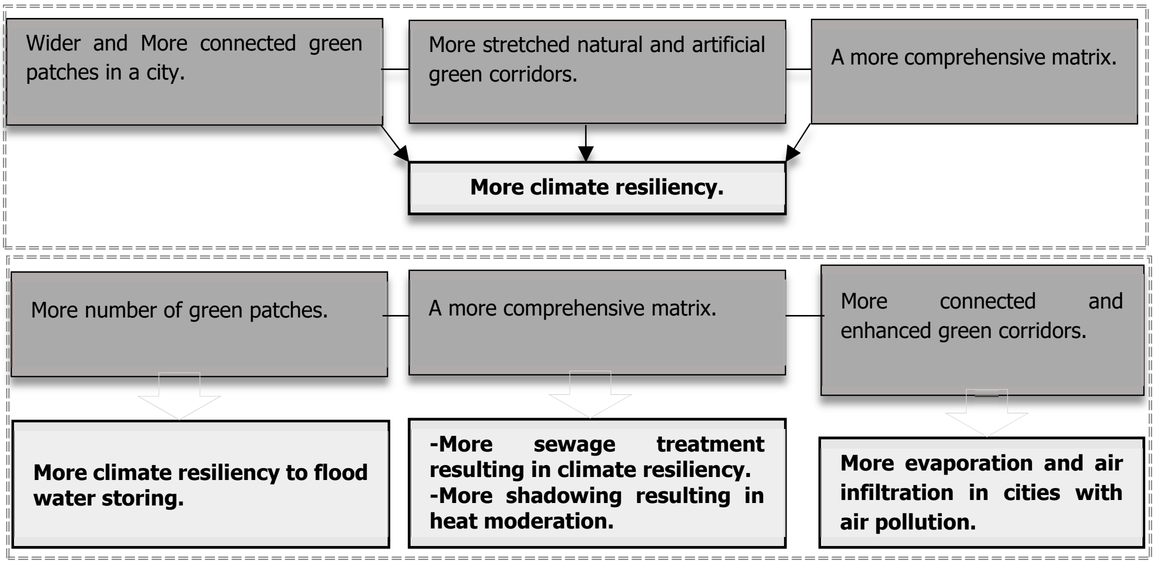

Fig. 5 Principles for analyzing UGI conditions based on their climate resilience role in a city through the language of landscape ecology (Patches, corridors and matrixes)

3 RESEARCH METHOD

In order to study the existing green infrastructure in a city scale, a valid method needed to be used. Norton (2015), has suggested a method to study and analyze the existing UGI, based on their potential to mitigate climate effects, in a city especially in the neighborhood scale. This is a 6 step framework to prioritize green infrastructure to mitigate mostly the high temperatures in urban landscapes.

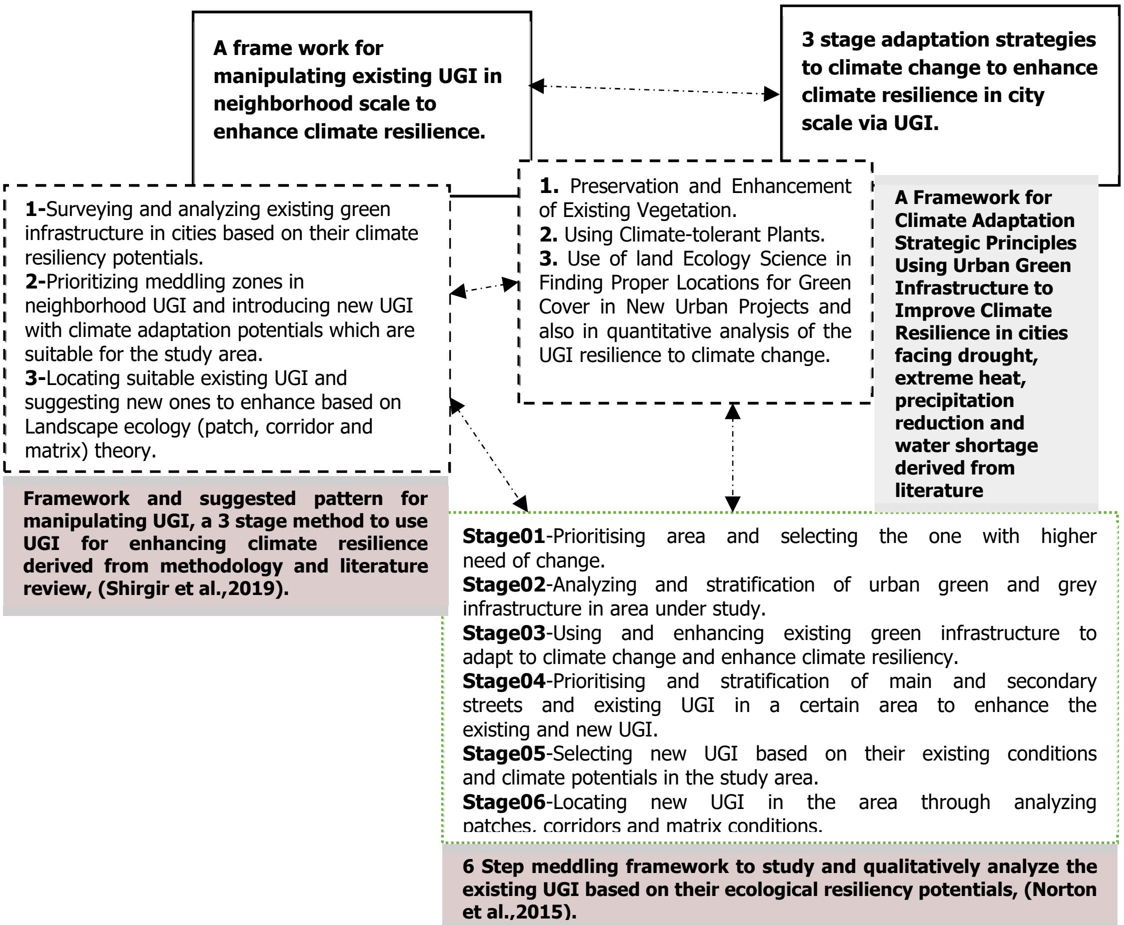

Fig. 6 Framework for meddling in UGI in city and neighborhood scale to enhance resilience to climate change

The 6 steps in a city scale are: 1. Prioritizing neighborhoods and choosing a neighborhood with a higher priority, 2. Identifying and categorizing green and gray infrastructure existing in the selected area, 3. Using and strengthening existing green infrastructure to adapt to climate change and increasing climate resilience, 4. Sequencing and prioritizing streets in the area of study based on strengthening of existing and new green infrastructure, 5. Selecting new and appropriate green infrastructure, taking current situation of neighborhood and its climate potential into account, 6. Accurately locating green infrastructure of the area by qualitative analysis of green patch, corridor and matrix situation (Norton et al., 2015).

Here, by combining, the 3 strategic principles derived from the literature review section (Gill et al., 2007) (Fig. 4), with the '6 step framework to qualitatively analyze the existing UGI based on their ecological resiliency potentials' (Norton et al., 2015), and landscape ecology principles to read the existing UGI in order to integrate climate resilience (Forman & Gordon, 1986) (Fig. 6), a method is produced in this research. In other words this combination, provides a framework and pattern, for manipulating UGI in city and neighborhood scale to enhance resilience to climate change (Shirgir et al., 2019).

3.1 AREA OF STUDY: YOUSEF ABAD NEIGHBORHOOD IN TEHRAN

Tehran is of the most suitable city for assessing the resilience to climate change. Due to global warming and rapid growth of the city and the population growth, the climate change has affected the city severely. As a result, the necessary measures should be taken into account on all factors affecting urban ecological resilience and especially, climate resilience. Given the climate change situation in Tehran, including air pollution, temperature rise over recent years, rainfall shortage and rainfall variations and decrease, lack of water resources and their decreased quality, increase of dust and drought, all quarters and areas of Tehran and the suburban areas are at risk of climate change (Sheikhi & Rafeian, 2016). As a result, conducting the study.

Fig. 7 Situation of plant species in Yousef Abad, Tehran (left), aerial image of Yousef Abad quarter (right) (Source. Author),(Aerial image Google n.d., 2019)

Yousef Abad area of Tehran is one of the old quarters of Tehran, located in the 6th district of Tehran (Fig. 7). UGI situation in Yousef Abad area was qualitatively analyzed and evaluated using the aerial images, GIS software and field surveys. This method and its results can change the scale from the neighborhood to the city and can be used to analyze the current situation in cities. It is important to clarify that based on the papers' main goal, the first 2 stages of the framework above were skipped to focus more on stages that would lead to the exact results.

4 RESULTS

The 6 stages that were used, are summarized in part A and B:

A) The first step taken here is a combination of stage 03 and 04 (Fig. 6). In order to use and enhance existing green infrastructure to adapt to climate change and enhance climate resiliency, the existing green infrastructure was documented on a map in Yousef Abad neighborhood of Tehran, to determine the type, position and situation of green spaces by conducting the field study, using the GIS software and aerial images (Bartesaghi-Koc, 2019).

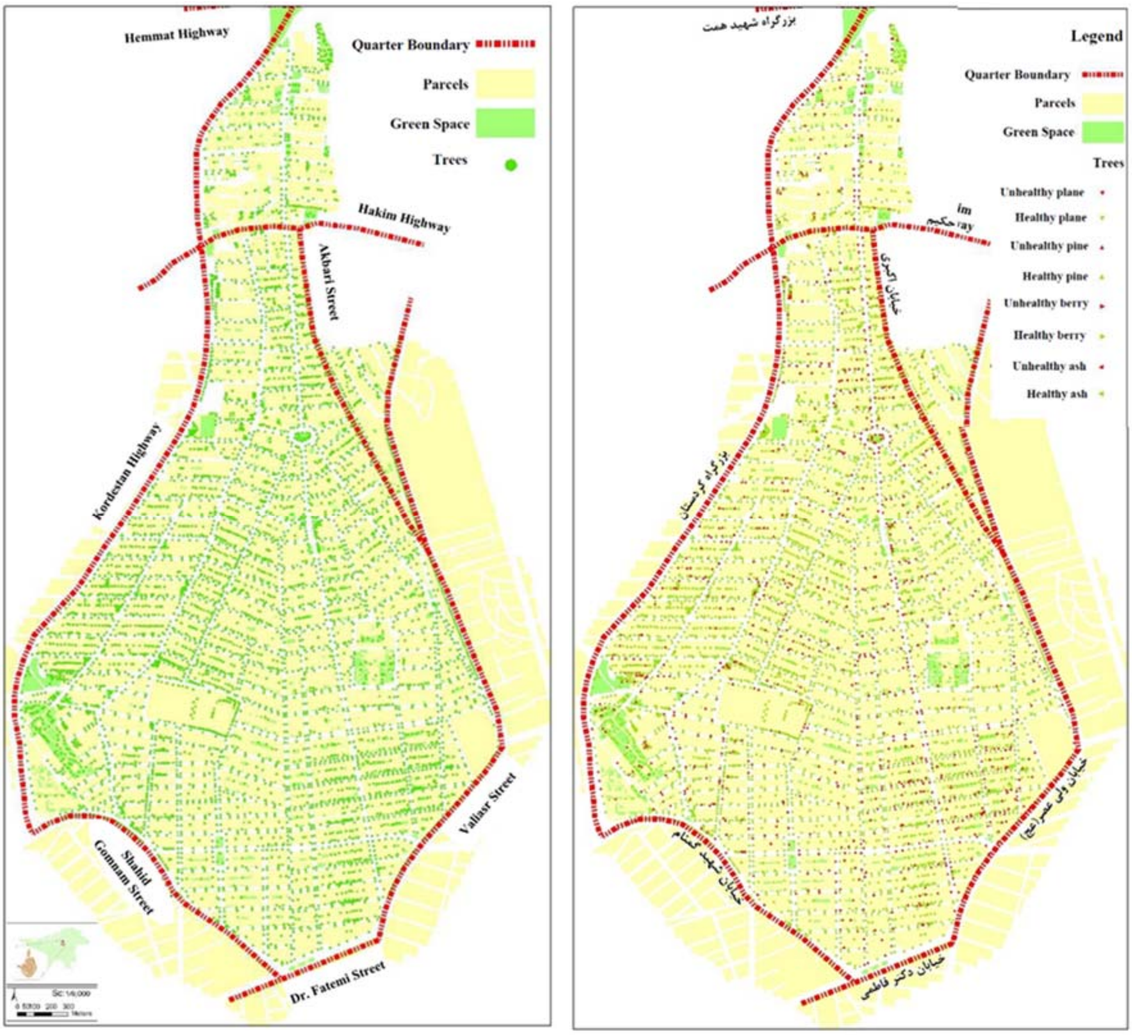

Fig. 8 Basic and analytical (qualitative) maps prepared from location of green infrastructure (left), type of plant species and their health status (right) using GIS

By examining the situation of green infrastructure in the related maps (Fig. 9), the existing plant species with their exact location, in this area, were specified. These species in some points are located in groups (masses=patches), in rows (green corridors), or individually. The analysis shows that, there is a great discontinuity (fragmentation) between them, along the Yousef Abad area. Also, by checking the health status of plant species, it was found that some of these species are unhealthy, which could reduce their climate enhancement capabilities. These species were also investigated based on their effective climate resilience potentials: water demand, air pollution resistance and shading (Norton et al., 2015), all of which can affect the climate challenges of the city of Tehran such as air pollution, drought, lack of water resources, and increased temperature. It is important to choose plant species based on their resilience potentials for future decisions. Also, the type, number and location of plant species were documented.

Stage 4, Prioritizing and stratification of main and secondary streets and existing UGI in a certain area to enhance the existing and new UGI, was qualitatively analyzed in field surveys and the results are documented in Tab. 2. Plant species were identified along with the scientific name, health status, water demand, air pollution resistance, shading, location (in the main and secondary roads) and the number of species are displayed in Tab. 2.

Tab. 3 is also presented, to introduce the suggested plants based on their climate resilience based on Stage 05 of the framework, 'Selecting new UGI based on their existing conditions and climate potentials in the study area'. In this table, the plant species are suggested to be replaced with unhealthy plant species or with low properties to reduce the climate effects, and proper positioning is determined according to their ecological characteristics.

SPECIES	SCIENTIFIC NAME	HEALTH STATUS	WATER DEMAND	AIR POLLUTION RESISTANCE	SHADING	LOCATION IN AREA	NUMBER OF SPECIES
Plane	Platanus Spp. (Platanus orientalis)	Unhealthy	High	Resistant	Low	Main/North-South	Dominant
Mulberry	Morus Spp. (Morus alba)	Healthy (Inappropriate for footpath)	High	Non-resistant	High	Main/North-South	Dominant
Tree of heaven	Ailanthus altissima	Healthy	Low	Resistant	Low	Main/North-South	Limited
Judas tree	Cercis siliquastrum	Healthy	Low	Resistant	Low	Main/North-South	Limited
Black locust	Robinia pseudoacacia	Healthy	Low	Resistant	High	Secondary/East-West	Limited
Field Elm	Ulmus carpinifolia	Unhealthy	Low	Non-resistant	High	Secondary/East-West	Limited
Eldar Pine	Pinus eldarica	Unhealthy	Low	Resistant	High	Main/North-South	Limited
Mediterranean Cypress	Cupressus sempervirens	Healthy	Low	Resistant	Low	Main/North-South	Limited
European Ash	Fraxinus excelsior	Healthy	Low	Non-resistant	High	Main/North-South	Limited
Fig	Ficus carica	Healthy	High	Non-resistant	Low	Main/North-South	Limited
Eastern Cottonwood	Populus deltoid	Healthy	High	Non-resistant	High	Main/North-South	Very Limited

Tab. 2 Qualitative analysis of UGI status in Yousef Abad area of Tehran based on climate resilience,(Shirgir et al.,2019)*

***-About the importance of location:** Prioritization of main and secondary streets are an important factor, since they display the amount of solar radiation, the streets are exposed to during the day, and how warm it gets. The streets that are northern-southern usually get more sun and are warmer therefore they need plants with higher shadowing capacity.

-Shadowing (shading) capacity: The amount of shade, trees provide depends on their architectural form and canopy density, these can all be listed in a field survey in small areas such as neighborhoods,(Pataki et al., 2011).Thick or dense canopy trees provide good shade, meaning that broad leaf trees are generally more effective than needle-leaf trees,(Norton et al., 2015).

-Tolerance to air pollution: Some trees are more tolerant to air pollution that's why they are a proper choice for a city like Tehran with severe air pollution challenge.

-Watering need: Also, water demand is an important factor, and the trees are water stressed. Stress from low water availability during hot weather can lead to defoliation and possibly death,(Gill et al., 2007).Therefore by examining the existing plants health status, it can be cleared that some plants are not suitable for the existing climate conditions and the amount of irrigation water available in the area (Coutts & Harris, 2013).

-Plants health conditions: Vegetation health information obtained from on-ground study and GIS based maps, can be used most efficiently to enhance existing UGI. Shading capacity in trees depends on both trunk and branches, as well as, the leafy canopy. Therefore the healthier the plants are the more shading and cooling benefits they will have, (Leuzinger et al., 2010).

-The data about green species climate resilience characteristics were derived from the book by H.Sabeti in 2008, called Forests, trees and shrubs of Iran and also from the author's knowledge of the green species characteristics based on her background in the field of landscape architecture.

SPECIES	SCIENTIFIC NAME	HEALTH STATUS	WATER DEMAND	AIR POLLUTION RESISTANCE	SHADING	LOCATION IN AREA	NUMBER OF SPECIES
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Tab. 3 Proposed plant species for Tehran Yousef Abad quarter with emphasis on increased climate resilience,(Shirgir et al.,2019)*

Shadowing (shading) capacity: The amount of shade, trees provide depends on their architectural form and canopy density, these can all be listed in a field survey in small areas such as neighborhoods,(Pataki et al., 2011).Thick or dense canopy trees provide good shade, meaning that broad leaf trees are generally more effective than needle-leaf trees, (Norton et al., 2015).

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-The data about green species climate resilience characteristics were derived from the book by H. Sabeti in 2008, called Forests, trees and shrubs of Iran and also from the author's knowledge of the green species characteristics based on her background in the field of landscape architecture.

B) Based on stage 06, 'locating new UGI in the area through analyzing patches, corridors and matrix conditions', the location and size of the patches, corridors and finally the matrix were reviewed here by analyzing the available aerial images (Fig. 9). In the existing situation (on the left), the green patches are fragmented and not fully connected, the number of them are also very limited. The green corridors have been disrupted and discontinued due to new building projects during the years, which has resulted in a broken green matrix in the area. Therefore in the suggested pattern, more continued corridors and patches and a more conformed matrix were suggested (on the right).

In Fig. 9, the situation of UGI was identified using the principles derived in landscape ecology. In the present situation of the area of study in Tehran, the current situation of the green patches, corridors and matrixes in the Yousef Abad neighborhood of Tehran in the right aerial image (current situation) is presented. The results from surveying location and size of green patches includes. In this area, after the construction of successive buildings, the green patches have been discontinued. These patches are fragmented and have a very weak connection. Based on the presented theoretical framework, the more continued and the greater number of corridors and the wider and more interrelated the patches, the more continued the matrix in this neighborhood, the higher the climate resilience of the area, based on the principles, the proposed model was provided in the right side in terms of the principles of landscape ecology (patch, corridor and matrix) for the Yousef Abad neighborhood.

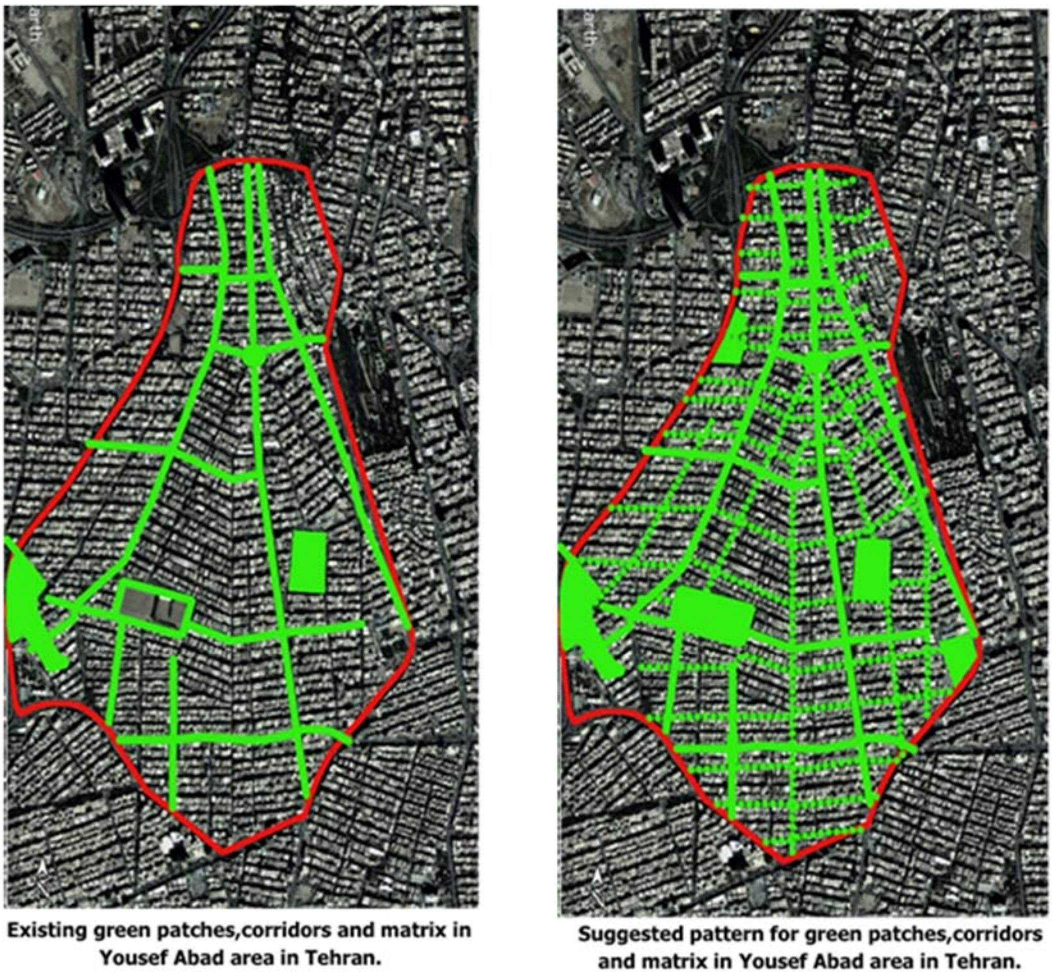

Fig. 9 Existing and suggested pattern green patches, corridors and matrix based on the science of landscape ecology (green patches, corridors & matrix) (Google n.d., 2019), (Shirgir et al., 2019)

5 DISCUSSION

In this paper, by going through the existing literature on UGI as a major climate change mitigation strategy, landscape ecology, urban climate change and urban climate resilience and on cities with dry climate facing drought, air pollution and lack of water resources etc., a major framework was produced by having combined the UGI climate change adaptation strategies with the 6 step method with landscape ecology theories, to study and analyze UGI, to manipulate UGI in cities and neighborhoods to enhance resilience to climate change and to reach a method and a pattern for a qualitative analysis.

This framework was later used as a practical method to study the existing UGI situation in a neighborhood in the city of Tehran, the capital of Iran. This method led to qualitative analysis of UGI status in Yousef Abad area of Tehran based on climate resilience and suggestion of new plant species based on their ecological characteristics and tolerance to specific climate conditions.

One of the important findings of this paper was that, climate resilience can be enhanced by introducing 'climate tolerant plants', whether drought tolerant or any kind of tolerance related to the climate challenge that a city is facing. This way climate resilience of the new or existing UGI can be ensured. This strategy can be specified to cities or neighborhoods facing drought and drier climates.

Choosing the right plant type is also very important, different plants survive in different climates and they vary in each city or region. According to the studies done for this paper, this step, which provides a list of plant species that could ensure resilience to climate conditions, has not been done officially as of today. This could be a step to further the studies done on UGI and urban resilience. It is important to say that, plant types, their location and health status of species are of great significance to reach higher resiliency.

Prioritization of main and secondary streets are an important factor, too. Since they display the amount of solar radiation the street is exposed to during the day, and how warm it gets. The streets that are northern-southern usually get more sun and are warmer, therefore they are in more need of plants that have shading capacities to cool the surfaces, that is another reason why shading capacities of plants are also surveyed on the field (Norton et al., 2015).The amount of shade, trees provide depends on their architectural form and canopy density, these can all be listed in a field survey in small areas such as neighborhoods (Pataki et al., 2011). Thick or dense canopy trees provide good shade, meaning that broad leaf trees are generally more effective than needle-leaf trees (Leuzinger et al., 2010).Also, water demand is an important factor, and trees are water stressed. Stress from low water availability during hot weather can lead to defoliation and possibly death (Gill et al., 2007). Therefore by examining the existing plants health status, it can be cleared that some plants are not suitable for the existing climate conditions and the amount of irrigation water available in the area (Coutts & Harris, 2013).Moreover, appropriate plant selection is very important (Tab. 3).

Implementing UGI is one of the easiest ways to modify street canyon microclimate other than façade awnings and overhangs to shade foot paths (Ali-Toudert & Mayer, 2007). Number of trees was qualitatively documented here, (dominant or limited), this is also to show which trees should be replaced and increased in numbers based on climate adaptation goals. It is clear that not all tree species possess the same capacities for heat and drought tolerance, a diversity of tree species can be important in moderating temperatures throughout the day, (Norton et al., 2015).

Regarding the green infrastructure in particular, it can be stated that the analysis of the situation of plant species in a region based on the type of plant species, location, covering area, number, area covered by them, health status of plant species, and comparison of these factors, can be a proper way to analyze the potential of climate resilience in the green infrastructure of an area in a city.

In principle, for the first time, in this research, a qualitative method was obtained for assessing the situation of green infrastructure based on climate resilience and changing of this green infrastructure in order to increase the climate resilience.

As displayed in Fig. 10, UGI's number, health status, type of species, location and covering area are the five important characteristics of UGI to assist with the analysis of climate resiliency. This diagram and its results can assist with 'qualitative' analysis of the above mentioned factors. More research must be done to result in more details of this analysis in a quantitative manor. For example a 'quantitative matrix' could be used to score the existing UGI in an area based on the five characteristics mentioned above, to do measurements based on quantities. In Fig. 10, to examine the qualitative characteristics of the gray infrastructure, some points are also presented which can be elaborated and completed in future studies.

These important factors can be categorized after the quantitative survey and measurement, and then, after overlaying the information about each factor, a general map can be achieved, which leads to a plan for deciding on the interference with the quality(and somewhat the quantity) of the existing and proposed green infrastructure.

By having reached these factors, the main question of the research: "How and based on which features of the green infrastructure can we assess and analyze climate resilience in a city? "Has been answered.

Other outcomes of this research are, using Forman and Godron's landscape ecology principles, as a reading language for a spatial interpretation of heterogeneity of the green patches, corridors and matrix. The design and location of UGI and on the whole their existing situation, can be translated into patches, corridors and matrixes in a city or neighborhood scale. This is a language that can be used to read the existing situation of UGI and to develop principles to enhance this situation into a more climate resilient city.

One of the most important points here is that the strategies and the method, that were mentioned earlier which are related to green urban infrastructure and their role on adapting to climate change conditions, can be applied to cities or neighborhoods and on the whole to countries facing four major climatic challenges which are: drought, extreme heat, precipitation reduction and water shortage.

Fig. 10 Effective qualities in assessment of urban climate resilience in terms of green infrastructure based on the language of landscape ecology, (Shirgir et al., 2019)

6 CONCLUSION

Climate change has a negative impact on urban-scale. Climate resilience is beyond the scope of urban planning and decision-making, but adverse climatic changes lead to a reduction in environmental resilience. Instead, there are variables for controlling and intervening in the environment such as the strategies for adaptation to climate change through urban green infrastructures which can be effective on climate resilience for the reasons mentioned before.

It is clear that climate changes are hard to control since they require a wide comprehensive global network of decision making. One way to somehow control and reduce these negative impacts is by interfering in green infrastructure in the cities by analyzing their existing conditions and evaluating their resilience potentials based on the way they are located and connected on one hand and the type of species they are composed of on the other hand and to later on, make suggestions for each city based on these qualities and quantities to enhance their resilience conditions. Also these principles can also be used for new projects and for making decisions about the green spaces and their species beforehand.

It seems that studies in the areas mentioned are less oriented towards improving the situation of the neighborhoods. To take the first steps, a neighborhood was selected here as the study area. In addition, standards, indicators and components for measuring resilience in this scale have not been properly elaborated. This could also be suggested for further studies on the issue.

According to the studies conducted in this research, it seems that so far, urban green infrastructure and their role in urban design and planning have not been properly cleared.

While it is proven that the use of urban green infrastructure is one of the key strategies to reduce and adapt to climate impacts in the areas with Mediterranean, hot and arid climates, the exact strategies for the correct use of these infrastructures in the cities have not yet been provided. Here, by conducting this research on the city of Tehran, a framework was obtained for documenting and measuring the quality of urban green infrastructures in order to improve the quality and location for the adaptation to climate change. These findings can be generalized to the cities and neighborhoods according to geographic location and their similar negative impact of the particular climate change which is mostly heat waves and extreme heat. More research needs to be done to generalize this method to other cities with other climate change challenges.

Also, there is still a gap for a *quantitative method* to assess climate resilience in cities based on green and even gray infrastructure and their characteristics, which can be found in future research. However, the scale issue is also important. Finding a quantitative-qualitative method for intervening in urban green infrastructure can also be considered for future studies to promote ecological resilience to climate change.

Analysis of the current situation, quantity and quality of vegetation, the way green infrastructure is located in the neighborhood, and the standards for achieving climate resiliency through this infrastructure can be part of the existing shortcomings in this area of study. Urban neighborhoods are considered as the best scale for applying new concepts of urban design and planning. Therefore doing a study on the neighborhood scale is a suggestion for further reading. And finally, using nature and its natural capabilities, is the best way to save the planet from the issues it is facing due to human actions.

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IMAGE SOURCES

Fig.1: Shirgir et al., 2019; Fig.2: Shirgir et al., 2019; Fig.3: Demuzere et al., 2014; Fig.4: Shirgir et al., 2019; Fig.5: Shirgir et al., 2019; Fig.6: Shirgir et al., 2019; Fig.7: Shirgir et al., 2019; Fig.8: Shirgir et al., 2019 & Google n.d., 2019; Fig.9: Shirgir et al., 2019.

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