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Application of resilience thinking to evaluate the urban environments; a case study of Tehran, Iran

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Abstract. Resilience thinking has recently been proposed as a different way of understanding the world and a new approach to managing urban environments. This research aims to evaluate the environmental quality of Tehran-Iran using some resilience criteria. Based on the comparative analysis of the current related theories, we have extracted and classified some of the resilience criteria into four dimensions, i.e. Pattern and process of socio-economic criteria in urban landscape, responses of human society in urban landscape, pattern of biophysical structure in urban landscape, and urban ecosystem dynamic and function. We have focused on the last two ones. The results show that the composition and configuration of urban green spaces and consequently its ecosystem quality do not fulfill the requirements of a resilient urban landscape. On the other hand, assessment of Tehran air quality shows that the number of unhealthy days has increased over the last decade. Also, Tehran has heavily relied on outer water basins. Besides, the proportion of impervious surfaces within a period of 22 years (1988-2010) has increased by more than two times. These results support the resilience criterion as a more realistic approach to demonstrating both the urban environments situation and the directions of future urban plans.

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1. Introduction

Resilience is a flexible concept which is currently used as an approach in different fields of study [1]. The concept of resilience was originally suggested as a descriptive ecological term [2]. Resilience is referred to as a basic capacity of an ecosystem to maintain desirable services of the ecosystem confronting environmental changes and human exploitation [3]. In another definition, resilience is presented as the capacity of ecological-social systems to attract disorders and also to maintain the feedbacks, processes, and necessary and

inherent structures of the system [4]. Resilience thinking, through the concept of multi-scale and selection of appropriate temporal and spatial scales, provides an insight to consider unpredictable future, inevitability of change, and vulnerability of such systems [5,6]. Resilience thinking provides a structured method for taking account of the complexities, uncertainties, and interdependence of systems and processes; it also paves the way for new methods of planning and more efficient application of assessment and sustainability thinking [7].

One of the most important concepts considered in resilience thinking is social-ecological system. Scholars, within the realm of resilience, have created the term 'social-ecological system' which includes cities. The term 'social-ecological system' elaborates on interdependence of human and nature, emphasizing the

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concept of humans-in-nature. Social-ecological systems include the integration of nature and human society with mutual feedbacks and interdependence. Although we cannot find a recognizable social or ecological portion in such systems, we cannot separate them for the purpose of analysis [8,9]. Influenced by the resilience thinking, new sources introduce urban ecosystems as the production of natural and social processes within which structure and performance are very closely related [10–13]. In cities and urban regions, with regard to the decisions made related to land use, we experience things such as structure changing, fragmentation and isolation of natural habitats [14], hydrological system failure [15], and changes of energy flow and food cycle [10], all of which lead to a reduction in resilience in different spatial scales making urban systems increasingly vulnerable. Thus, it can be concluded that we can improve the ecological performance and consequently resilience in urban habitats through establishing a reform in the urban structure.

In the assessment of urban resilience, the system, as a whole, is regarded; not a specific kind of disorder or specific aspect of the system that might be affected [16]. Instead, the general performance of the system will be evaluated with regard to the resilience criterion. Different criteria have been developed to determine the general resilience of the system. Vanoudenhoven presented a list of social-ecological indices (criteria) for landscape resilience; however, their indices (criteria) concentrate more on agricultural landscapes [17]. In addition, some studies have been performed on the assessment of resilience in social-ecological systems with rural nature. Walker and Salt developed some criteria, presented in their book, entitled “Resilience Thinking”. Nine criteria were suggested for assessment of resilience including ecological diversity; ecological variability; modularity; economic-social system diversity (social capital); overlap in different levels of governance; tight feedbacks (political, social, economic, and environmental conditions); unpriced ecosystem services (diversity of such services); acknowledging slow variables; and innovation. Resilience World Alliance as well as some researchers developed some other criteria including diversity, openness, inter-relationship of feedbacks, reserves, and modularity [6,7,16].

In the present study, based on the characteristics of urban systems and interaction of subsystems in urban regions [10–13,18,19], these criteria were classified into four groups including pattern of biophysical structure, pattern and process of socio-economic criteria, urban ecosystem dynamic and function and responses of human society in urban landscape. Resilience criteria and their application in urban environment, with regard to the literature related to general resilience criteria in urban environment, are all shown in Table 1.

The current study emphasizes that assessment of general resilience of Tehran needs to take into account a lot of resilience criteria, but in this research the considered criteria include pattern of biophysical structure in urban landscape and urban ecosystem dynamic and function. The composition and configuration of urban green spaces, as the most important component of urban ecosystems, and also the biophysical variables such as air, water resources, and impervious surfaces are considered as the basic factors of urban ecosystem services.

2. Material and method

The current study selected Tehran as a case study; in addition, its resilience was assessed. Based on Statistical Centre of Iran, the population of Tehran was more than 8 million in 2011, the first most populous in Iran. According to the results of the public census in 2011, the population of the province of Tehran was about 12,183,391, which showed an average annual growth rate of about 1.44% [20].

Based on the suggestions made by the Resilience World Alliance for the assessment of resilience [16], the following steps were taken for assessment of resilience of Tehran:

1. Defining appropriate measures to assess the criterion (landscape metrics). Table 2 shows appropriate measures for each criterion;
2. Mapping measures;
3. Description of the main system with regard to the resilience assessment criteria;
4. Interpretation of Tehran's resilience based on the results achieved through metrics.

For measuring the landscape metrics or appropriate measures for the criteria, software FRAGSTAT 4.1 was used. This software makes it possible to calculate landscape metrics [21]. In the present study, FRAGSTAT 4.1 software was used to calculate landscape metrics. Using this technique can reduce the errors resulted from the calculation of the metrics through the software. In addition, it makes it easier to interpret the metrics because it shows the results of the metrics calculation as zoning map.

In this study, land cover maps in three classes of green, open, and built up area were extracted from Landsat TM images that surveyed in June, 1988 and 2010 through TM sensor. The following steps were taken in order to achieve land cover maps: after getting satellite images, the process of geometric match and also making coordination between the images through vector road maps of Tehran were performed to prepare data for the purpose of processing and exploiting of information. The second sampling was done using the

Table 1. Summary of criteria for assessment of general resilience in urban landscape.

Criteria category	Criteria	Feature of criteria with urban landscape
Pattern of biophysical structure in urban landscape	Diversity of structure pattern	Spatial diversity in habitat patches that are source of supply of ecosystem services in urban landscape
	Modularity of structure pattern	Spatial and temporal configurations of structure that are sources of supply of ecosystem services in urban landscape
	Connectivity of structure pattern	The presence of ecological networks (greenways, green belt)
Pattern and process of socio-economic in urban landscape	Diversity	Diversity of urban land uses
		Presence of institutions and social networks
		Diversity of social interactions
		Diversity of economic opportunities
	Social capital	Diversity of economic resources
		Presence of strong social networks in urban locals
		Diversity of governmental structures and executive levels of urban management
Urban ecosystem dynamic and function	Modularity	Flexibility and diversity in institution structures
	Openness	Reasonable openness of society to respond to changes
	Diversity of the main kinds of ecosystem services	Diversity of the types of ecosystem services or slow variables that are good for urban landscape
		Regulating services
		Supporting services
	Tight feedbacks	Long-term policies and local solutions to improve ecosystem services and reserves
Responses of human society in urban landscape	Unpriced ecosystem services	To be aware of costs for monitoring and active management of Un priced ecosystem services
	Ecological variability	Internalizing external costs of loss of ecosystem services
		Preparation and knowledge of society for the origin of internal and external disturbances
	Innovation	Providing the context for experiencing new priorities of the stakeholders in urban local area

Nearest Neighbor interpolation (NN) method. All the bands used here were geometrically matched using the above method with RMSE 0.47. Spectral modification of the images aimed to highlight the phenomena and also to improve the quality of the images. Then, using a combination of the bands 4, 3, and 2 we did the supervised classification through maximum likelihood method. Accuracy assessment was done after classification using ground truth map; therefore, the overall accuracy index of %85 and Kappa index %89 were achieved. The results were considered satisfactory. In

the interpretation of data, the land use maps with 1:2000 scale and personal experiences of field surveys were used. Figures 1 and 2 are of landcover in three classes of open, green, and built.

3. Results

As mentioned above, the present study aims to analyze resilience of Tehran according to pattern of biophysical structure and urban ecosystem dynamic and function criteria.

Table 2. Landscape metrics for assessing resilience of Tehran based on pattern of biophysical structure and urban ecosystem dynamic and function.

Dimensions of urban resilience	Criteria	Measurable variables or data	Metric
Pattern of biophysical structure criteria	Diversity or spatial heterogeneity	The amount of green and open patches coverage	Patch Richness Density (PRD)
		Number of green and open patches	Percentage of Landscape (PLAND)
		Richness of green and open patches	
	Connectivity	Mean distance between each class of patches	Euclidean Nearest-Neighbor Distance (ENN)
			Radius of Gyration (GYRATE)
	Modularity	Amounts of heterogeneity or homogeneity of urban green and open patches	Contagion index (CONTAG)
Urban ecosystem dynamic and function	Unpriced ecosystem services	Air quality	The number of clean air days during the entire year
		Water resources	The quantity of water resources
		Change of impervious surfaces	Change in ratio of impervious surfaces

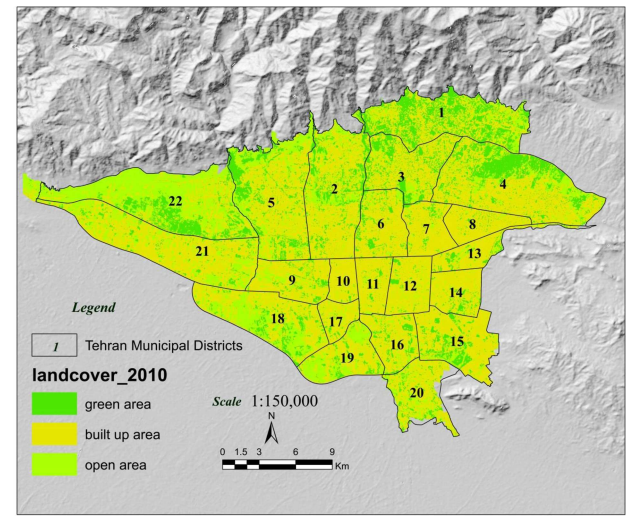


Figure 1. Land coverage map of Tehran-Iran from Landsat satellite 2010 (landcover_2010).

The pattern of biophysical structure is related to patches originated from environmental services. For our analysis, it was based on green patches with environmental service origin. Our criteria include diversity, connectivity, and modularity. The results are presented in three parts according to these criteria.

3.1. Diversity (spatial heterogeneity) of the green patches in Tehran

Diversity (spatial heterogeneity) of green patches in Tehran was assessed with two metrics of patch area (PLAND) and Patch Richness Density (PRD).

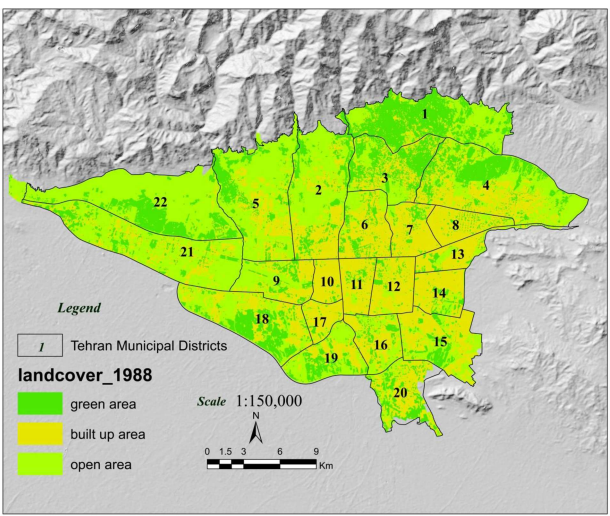


Figure 2. Land coverage map of Tehran-Iran from Landsat satellite 1988 (landcover_1988).

3.1.1. The ratio of green patch areas in Tehran
Patch area is one of the most important metrics to measure landscape composition, specifically to show how much of the target patch type (green patches) exists within the landscape (Tehran). Figure 3 shows the area of green and open patches and their distribution. As shown in Figure 3, in few parts of Tehran, the ratio of green and open patch areas is %50 or more.

3.1.2. Green patch richness density in Tehran
In this metric, we divide the number of all kinds of patches in the city by the whole area of the landscape. The unit of this metric is the number of patch types in

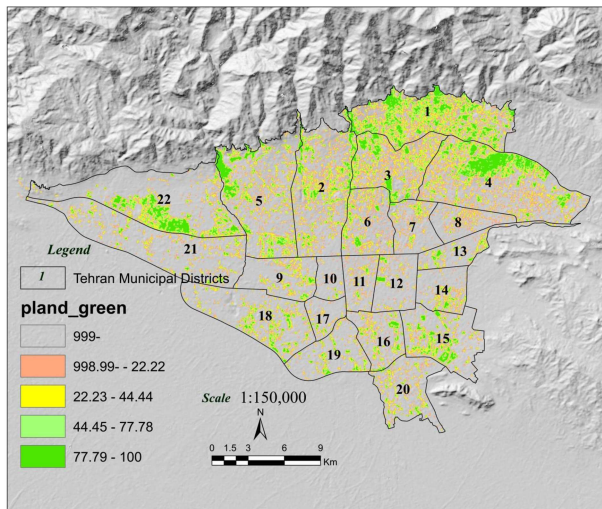


Figure 3. The ratio of green patch areas in Tehran (pland_green).

100 ha. This metric, concerning a particular patch type (e.g. green patches in urban landscape), may affect a variety of ecological processes in this landscape, such as biodiversity. The number or density of patches is probably mostly valuable as the basis for computing other more interpretable metrics. Through this metric, we can compare different landscapes. As shown in Figure 4, the higher the result of this metric, the richer is that area with regard to green patches.

3.2. Connectivity of green patches in Tehran

Connectivity of green and open patches in Tehran was assessed using Euclidean distance to nearest neighbor (ENN) metric and intensity of the patch (GYRATE) metric.

3.2.1. Euclidean distance to the nearest neighbor of green patches

This metric shows the average of the shortest distances between patches of the same type within the landscape. This metric computes the shortest straight-line distance between the focal patch and its nearest neighbor of the same class. The unit of this metric is meter. This metric was computed for all the green patches of Tehran. In Figure 5, the average distance of Euclidean neighborhood of green patches in Tehran is demonstrated. As can be seen in the figure, the average neighborhood distance of green and open patches in Tehran is more than 63 meters.

3.2.2. Intensity of green patches in Tehran

This metric, for each patch, is calculated as the average distance between each cell in the patch and the center of the patch. The unit of this metric is meter. Intensity of the patch (GYRAT) is a technique to measure the extended area of patches (or their intensity). It shows how far across the landscape a patch can extend its reach. This metric, for each patch, is calculated as the

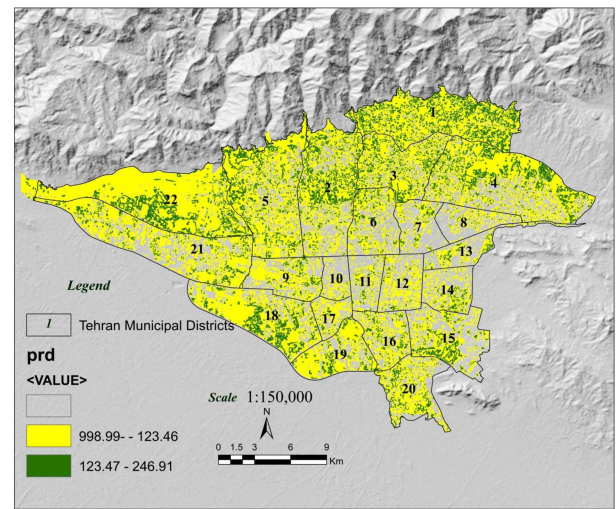


Figure 4. Green patch richness density in Tehran (prd).

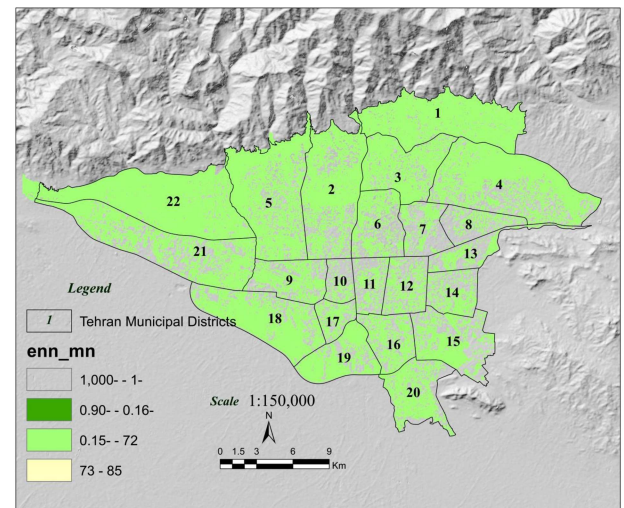


Figure 5. Euclidean distance to the nearest neighbor of green and open patches (enn_mn).

average distance between each cell in the patch and the center of the patch. Then, it is summarized, for all the patches or patches of the landscape, as the average of the weighted area. When aggregated at the class or landscape level, radius of gyration provides a measure of landscape connectivity. This metric is considered to be zero in scattered areas. In Figure 6, the intensity of green patches in Tehran is shown. As can be seen, the area of patches is mostly less than 28 meters. Just in some specific parts, such as region 1 or 22 and some parts in the south including agricultural lands, the intensity of the patches is 28-36 meters.

3.3. Modularity of green patches in Tehran

The metric of contagion was used to analyze modularity in Tehran. This metric shows the composition and texture of land cover. Contagion metric measures both patch type interspersion and patch dispersion at the landscape level. Based on the result obtained from this

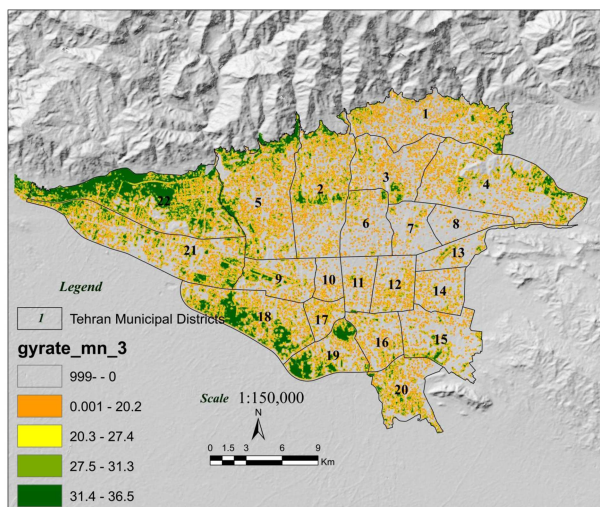


Figure 6. Intensity of green patches in Tehran (gyrate).

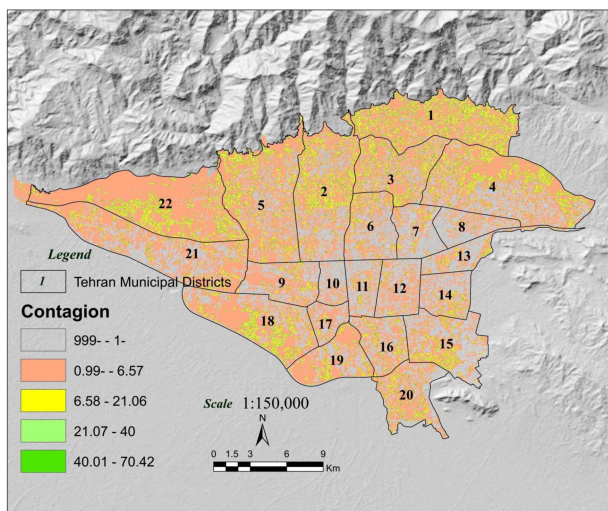


Figure 7. Modularity of green patches in Tehran (contagion).

metric, we recognized the extent to which patch types are aggregated or clumped. The unit of this metric is percentage. The metric of contagion is a measure showing green patches in Tehran, which is contagion in a cluster-like manner in an accumulative way or is scattered around the city as smaller patches. Higher values of contagion may result from landscapes with a few large contiguous patches, whereas lower values generally characterize landscapes with many small and dispersed patches [14]. In other words, if the result is close to zero, it indicates that the green patches are small and scattered and if it is close to 100, it shows that the patches are accumulated in one place and they do not have a congruent distribution in the urban landscape of the city. As can be observed in Figure 7, there is no 100 as a result of contagion metric; the places with 40-70 have acceptable contagion and there is a balance, in these places, between connectivity and

contagion. Areas with a contagion of less than 20 are the places suffering from lack of connectivity, as well.

3.4. Urban ecosystem dynamic and function

Urban ecosystem dynamic and function is about diversity of types of ecosystem services or slow variables that are good for urban landscape. The biophysical variables such as air, water resources, and impervious surfaces are considered as the basic factors of urban ecosystem services.

3.4.1. Air quality of Tehran

Air pollution is one of the serious problems in Tehran. The number of clean days from 2007 to 2011 has been 23, 13, 32, and 14 days, respectively. Over these years, the healthy conditions were only observed in the 327th, 293th, 291th, and 247th days, respectively; in addition, the days considered as unhealthy were the 15th, 59th, 40th, and 103th, respectively. The very unhealthy conditions did not occur in 2007; however, in years spanning from 2008 to 2010, only one day with dangerous and unhealthy condition was experienced. Generally, concerning the PSI index from 2007 to 2009, the pollution states had a trend showing the conditions as becoming unhealthy [20].

3.4.2. Water resources quantity

Instability situation of Tehran water resources has occurred due to the dry hydrologic conditions in Tehran region (average precipitation of about 250 millimeters per year), accompanied with high population density, changing climates, and lack of balance between water supply and demands. The trend and associated changes in the total water consumption in Tehran from 1998 to 2010 has been upward and incremental; moreover, the consumption has risen from 886 million cubic meters to 1033 million cubic meters. The average annual growth rate of this index rose by 0.74% within this time span [20]. In order to provide the fresh water supply for the urban and agricultural consumption in Tehran, several dams have been constructed on the flowing rivers including Karaj (Amir Kabir dam), Lar Dam, Latian, and Taleghan Dams. It is significant to note that Tehran has heavily relied on the outer water basins. Figure 8 shows the situation of Tehran's dams. Lar Dam and Taleghan belong to other basins.

Moreover, the ground water aquifers are considered strategic resources in the arid regions. In case of Tehran, the importance of ground water aquifer, due to water shortages in the surface water, has increased substantially. The drop in annual average water level in Tehran plain is about 18 centimeters in year [20].

3.5. Change in ratio of impervious surfaces

This is based on the interpretation of Landsat images taken from the city in the 2 mentioned years. The

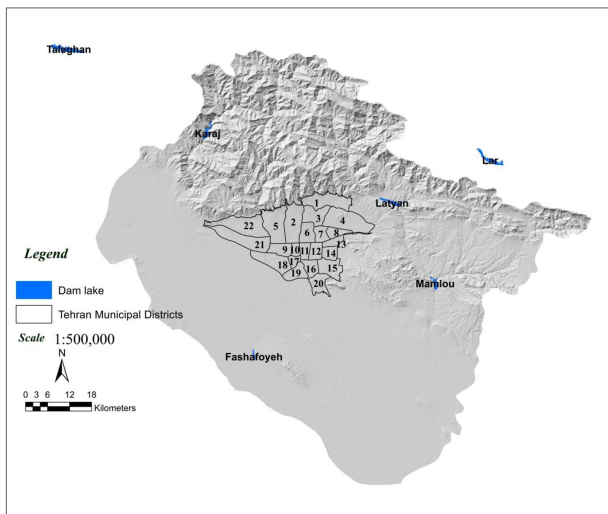


Figure 8. The situation of Tehran dams (dam lakes).

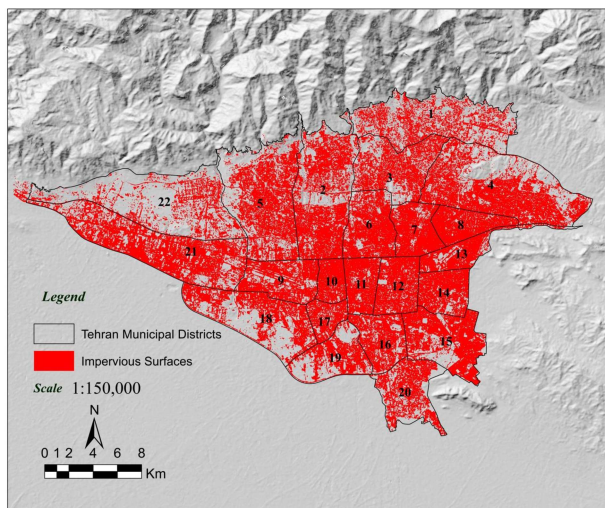


Figure 9. The impervious surfaces in 2010.

green land area and open space areas have constantly and gradually decreased and the area has been taken by construction of buildings. In 1988, only 37% of the present area of Tehran was built on and constructed while in 2010, it increased to 61%. Figure 9 shows the impervious surfaces in 2010.

4. Conclusion

Survival of the cities as social-ecological systems depends on natural and ecosystem services. As a result, getting to know resilience in urban environment needs interdisciplinary understanding and an analysis in different scales. Among the criteria defined for assessment of resilience of urban ecosystems, we can refer to diversity, connectivity, and modularity of structural elements with ecological performance (green patches); also, the main ecosystem services can be regarded as some other criteria. Based on the results

obtained from metrics of distribution diversity of open and green patches (PRD and PLAND) in Tehran, the ratio of green and open patches areas is more than 50 only in few regions and has appropriate intensity. These regions are mostly in the northern part of the city or in the south, where agricultural lands exist. The results obtained from connectivity metric (GYRATE and ENN) indicate that only in few regions the edge to edge distance between the patches is inconsiderable. The results achieved from CONTAG metric, focusing on spatial distribution of green and open patches (modularity), show that in most of the region, we experience low contagion due to low connectivity. In few regions, where the connectivity is considerable, the percentage of contagion is high. From the results achieved from three criteria of diversity, connectivity, and modularity – which in their own turn show resilience of Tehran with regard to ecosystem criteria – we can conclude that combination and spatial distribution of the green patches are not resilient in Tehran. The state of ecosystem services (air, water, and the ratio of impervious surfaces) does not fulfill the requirements for a healthy urban structure to support a resilient landscape. Assessment of resilience in urban environments based on the abovementioned criteria is a guideline for authorities and decision makers to use flexible and modern approaches in urban management. Consequently, the current study indicates that Tehran is not a resilient city regarding the pattern of biophysical structure and ecosystem services criteria, which means that proceedings of Tehran municipality, regarding the green space, air, water, and urban development management, have not been efficient so far and their performance cannot be guaranteed. Achieving resilience needs cooperation between and within organizations, matching the organizations responsible for making decisions with ecological scale of the recognized source to prevent one sided views.

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