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Restoration and Reclamation of the River Valleys' Landscape Structure for Urban Sustainability using FAHP Process, the Case of Northern Tehran- Iran

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ABSTRACT: Tehran city has been subject of critical environmental challenges during the course of 20th century namely: massive population growth, broad expansion, reduction in urban open/green spaces, increasing in energy consumption and waste production. Releasing industrial wastewater into river valleys have led to considerable changes in structure of city's natural landscape. The natural structures of river valleys in northern Tehran that historically function as ecological corridors for transferring surrounding air and water into city, helping urban sustainability, have been gradually turned into large concrete canals for urban wastewater to downstream land, damaging ecosystems balances and biodiversity needs. The eradication of green spaces on the river banks accelerated the rivers environmental degradations. This research aimed at examining the structure of northern Tehran landscape and the influential factors which play role in the river valleys' landscape destruction. The contributing parameters to restoration of these ecological corridors were investigated based on a tree structure. Using FAHP-Fuzzy Analytical Hierarchy Process- the questionnaires distributed among experts, and factors were classified. Then Chang's methodology employed and finally ranked by degree of importance. Outcomes of FAHP were used as input for Arc GIS 9.3 to export the analytical maps of Tehran's urban landscape enhancement through river valleys' restoration. Evidence from this research show that alteration in environmental structures(vegetation cover, micro climate, urban infrastructures, hydrology) comes with greatest importance in shaping existing changes. Restoration of river valleys' structures are therefore, possible through improving their natural functions i.e. biological structures, urban green patches and enhancing network connectivity among patches.

Keywords: FAHP, Landscape complexity, Ecological planning, River valley, Tehran city,Urban landscape infrastructure,Urban sustainability

INTRODUCTION

Tehran the capital city of Iran has been subject of severe environmental problems as a result of rapid urban development during the 20thcentury. Massive population growth, overall city expansion, reduction in open and green spaces, increasing in energy consumption and waste production, and releasing industrial wastewater into river valleys are seen as few consequences of such rapid development. These, have resulted in considerable changes in structure of city's natural landscape and built environment. However, landscape is considered as an example of ecological complex systems and interacts with the larger environmental parameters and structures that should be taken into account in the urban environmental dynamism (Li, et al. 2015; Masnavi, 2013; Masnavi and Soltanifard 2007; Green et al. 2006).Some research discussed the role of planning in ecological networks and maintain that planned ecological network would reduce landscape fragmentation, and increase the shape complexity of green space patches and

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landscape connectivity which in turn would improve the quality of the urban ecological environment(Li, et al. 2015).The natural structures and landscape of river valleys in northern parts of Tehran, has been functioning as the ecological corridors for transferring surrounding air and water into city center and helping urban sustainability. However, during the past decades they have been gradually turned into large concrete canals to transfer urban wastewater into downstream land and hence, have lost their environmental functions and ecosystem services;these provided them with a poor or lack of biodiversity. Thesehas also contributed to the eradication of green spaces and encouraging construction development on the river banks; and accelerating damages to the river landscape and environmental degradations. This critical environmental conditions in Tehran and lack of green patches in its urban landscape necessitate the development of sufficient green spaces and improving their ecological roles and functions (Wolch et. al. 2014, Ernstson 2012). Vital role of green corridors in urban sustainability proves the need for their connectivity while taking into account their landscape setting, location of green patches and their interrelation with built and natural corridors. Moreover, the river valleys in city provide connectivity between urban green space and other open spaces, and their importance as natural structures and green corridors have been acknowledged in the works of many scholars. The green ways along the rivers, streams, and river valleys form the natural corridors which have crucial role in water quality conservation and environmental quality enhancement. In addition, the connectivity among these corridors is essential for maintenance of biodiversity as well as sustainability of urban ecosystems; where, suitable places are provided for recreation, and communicating with nature for peoples. (Valencia-Sandoval et al.; 2010; Ustundag et al. 2011). Under circumstances, the ecological networks idea is argued as a practical approach toward realizing these concepts (Li *et al.* 2005; Fennell and Butler 2002). A green ecologic network is claimed to restrict the city expansion in future,enhancesthe urban environment quality, and provides natural habitat for birds and animals (David, 2007). Green ecologic network consist of green nodes, parks and green corridors. The green nodes include parks, gardens, woodland patches, rivers and wetlands (Vairavamoothy, 2009). The green nodes and corridors form an integrated green ecologicalnetwork which connects city center, woodlands, mountains and suburbs together. In these regions, green spaces should be reinforced through increasing green/vegetation covers which implies enhancing ecosystems services and environmental qualities (Wolch et al.; 2014; Randhir2005).

On the other hand, the social, economic, political and cultural changes during past decades have led to new form of social and cultural relations in many capital cities around the world. City, as the spatial manifest of these alterations, cannot resisted the changes and expressed consequently the modified spatial relations and modern issues of civil society. Since these metamorphoses are taking place gradually due to external factors (and not internal ones), the city matrixcannot be well prepared and adapted with the urbansociety's environmental needs. In the case of Tehran, there is a contradictions between ecological structures (including morphology, flora and fauna hydrology etc.) in one hand, and the built environment on the other,clearly observable. As a result, the city has lost its historic identity and turned into a plastic form that follows and expands along with the directions of connecting roads (Vallés-Planells et al. 2014; Zarrabi, 2014).

Location of Tehran, on southern footsteps of Alborz mountain range, provided the city a specific feature. The city proximity to the mountain has led to formation of numerous valleys with natural-ecological potentials that have distinctive connectivity forms in different parts of northern ranges(Bemanian 2008; Yavari 2007). It introduces green space patches into city, straight green belts that determine the boundary of city and nature and at some points, and expansion of green corridors along the city transportation routes(Tremblay, 2013).

Presence of river valleys on northern parts of Tehran has several advantages. In spite of environmental benefits, they provide places to fulfill residents' recreational needs (Dai, 2011; Shafii et al. 2003) and mostly tourism, mountain climbing and hiking opportunities. The main river valleys, located in north of Tehran, are including:Darabad, Jamshidiyeh, Tang Hesarak, Golabdareh, Darband, Velenjak and Darakeh, Farahzad and Kan. Water flow of these rivers has favorable effect on ground water recharge in low-land plains. However, this natural procedure is threatened currently by garbage disposal, waste water release and construction on the banks. Other challenges include clear cutting of vegetation cover, soil erosion, decrease in biodiversity richness etc. Regarding northern river valleys in Tehran, the major problem is the conflict between human activities (residential, recreational, industrial etc.) and nature/ landscape conservation (Bozorgiet al. 2005;Pourjafar 2010).

Different aspects of urban river valleys have been studied and this research focuses on those researches conducted in European countries. These studies reveal invaluable experiences about reclamation and

restoration of river valleys in cities, comprising not only comprehensive and general principles, but also local and specific approaches toward the issue (Soliman,2012). Discussed perspectives mostly include following points:

1.Planning and Implementation Process
2.Reclamation Techniques
3.Ecological, Social and Economic Effects
4.Aesthetic Assessment
5.Social Assessment and Public Participation
6.Performance Control and Success Indicators (Ryan, 2011).

Some of these research were studied and their findings are summarized and compared in Table 1.

River valleys in Tehran are the main elements forming the urban morphology and also contributing to urban ecological capacity and landscape sustainability. Recently, special attention is given to the restoration of seven river valleys in Tehran; however, the emphasis placed on "Increasing the area of urban recreation spaces without expanding impervious surfaces". This research aimed at incorporating, classifying and analyzing the major factors contributing restoration of river valleys in Tehran according to experts` knowledge (Macias Fauria, 2013).

MATERIALS & METHODS

Tehran is located at 35°412 463 N, 51°252 233 E and its elevation varies from 2000 m at highest northern lands to 1200 m in center and 1050 in lowest plains. This city is located between mountain (in north) and desert (in south) and generally spread on the southern hills of Alborz Mountain ranges(Fig.1). South of Tehran is restricted by Rey and BibiShahrBanou mountains and also by Shariar and Varamin Plains in west and east respectively. The north of the city is limited by mountainous hills and in the meantime it is surrounded by some faults such as Mosha, north Tehran, Rey, Taleghan, andIvanaki faults.Moreover, there are 12 water basins upstream of the city and also 14 Km flood-causing strips from Darabad to the west of Farahzad Valley (Atek, 2011).

Table 1. Some river valley restoration programs in European cities (Jones, 2013)

Research	Results
The banks of the Rhone river 2006 (les berges du Rhone 2006)	Major part of Rhone urban river`s bank is planned by city (Lyon) administrative, comprising an area around 60000 square meter. The space is assigned to new landuses.
Nature val de saone, Municipalities along the saone river inel. (Lyon, 2004)	The purpose of this project was restoration of green space and vegetation cover on banks of Saone urban river, aimed at improving the quality of vegetation cover. This plan started in 1999 and its accomplishment lasts for a few years.
The Blue Network (Het Blauw Network, 1998), Brussels	This plan aims at restoration and reclamation of various urban streams in central part of Brussles, including: Neewpedebeek, molenbecknord, Molenbecksud (Geleytsbeek), la woluwe, Vogelzangbeck and the Brockbeek. This project focuses on hydrological and ecological restoration of river corridors and their visual functions (Het Blaw network 1998).
Trout 2010, Hamburg	Trout 2010 is a program for rehabilitation of residents in a trout aquaculture region along the selected Hamburg`s ravines. Projected improvements require non- governmental cooperation. This project is in accordance with Agenda 21 guidelines for urban planning.
Emscherumbau	Mining excavation history in Emscher region defines the nature of urban ponds in RuHR. This plan is under implementation since 1990 and aims at restoration of all urban ponds in the region to achieve sustainable water consumption and provision of future water needs.
Isar Plan, Munich	Isar project has been started since 1995 and is a joint program between Bavaria province and Munich in order to boost the resistance against flood, improvement of ecological status and restoration of values in Isar river in Munich till 2006.
Stream concept of the city of Zurich, Zurich	The concept of "Sanitary Water" refers to separation of non-contaminated water from sewage canals in order to restore the ravines. The purposes are purification of ravines, enhancement of ecological values and their restoration in urban areas of Zurich.

The weather in Tehran is influenced by mountains in north (Tochal breeze) and dry plains in south. Hence, it is partially moderate and humid in northern parts and hot and dry in other regions, occasionally cold in winters. Precipitation is mostly due to Mediterranean and Atlantic winds blowing from west. It is noteworthy that AlborzLowercaseimpede the penetration of most air masses, consequently there are two micro climates were formed in Tehran: moderate in north and dry in south(Ibid).

A variety of factors contributing in examining the structure of river valleys in Tehran. FAHP(Fuzzy Analytical Hierarchy Process) was therefore utilized as an appropriate method for pair wise comparison and detailed analysis of the problem. In the first stage, a questionnaire was designed and distributed among 15 experts of different disciplines including environmental design, urban planning, urban design and environmental planning. This method was employed by Chang (1992) where he used it to analyze the results of questionnaires according to fuzzy analytical hierarchy process. The method integrates arithmetic mean of experts' judgments, Saati's normalized method and fuzzy triangular numbers. The steps of Chang's extent analysis can be given as in the following:

Step1. Designing the hierarchy structure: the general structure of decision making tree is determined according to goal, criteria and alternatives.

Step2. Forming a pair wise comparison Matrix: according to the decision- makers'judgment, the matrix can be filled by fuzzy triangular numbers:

$$t_{ij=(a_{ij},b_{ij},c_{ij})} \quad (1)$$

Where A_{ij} in the matrice is the number of experts ranking priority of variable i and j.

Step3. Calculating the Arithmetic mean of judgments: arithmetic mean of decision- makers' answers can be achievedusing following equation:

$$A = \begin{bmatrix} (1,1,1) & \dots & \begin{Bmatrix} d_{1n1} \\ \dots \\ d_{1np_{1n}} \end{Bmatrix} \\ \dots & \dots & \dots \\ \begin{Bmatrix} d_{n11} \\ d_{n12} \\ d_{n1p_{n1}} \end{Bmatrix} & \dots & (1,1,1) \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} (1,1,1) & \dots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{n1} & \dots & (1,1,1) \end{bmatrix} \quad (3)$$

Step4. Summing up each row of fuzzy comparison matrice:

$$S_i = \sum_{j=1}^{n} a_{ij} \ , i = 1,2,..,n \quad (4)$$

Step5. Normalizing the row sums as below:

$$M_i = S_i \Phi [\sum_{i=1}^{n} S_i \quad , \ i = 1,2,....,n] \quad (5)$$

Describing as (l_i , m_i , u_i), the overall steps can be expressed as this formula:

$$M_i = \left(\frac{l_i}{\sum_{i=1}^{n} u_i}, \frac{m_i}{\sum_{i=1}^{n} m_i}, \frac{u_i}{\sum_{i=1}^{n} l_i} \right) \quad (6)$$

Step6. Computing the degree of possibility for each μ_i, d'(A_i), and estimating the priority.

The degree of possibility for triangular fuzzy number $\mu_2=(l_2,m_2,u_2)$ to be greater than $\mu_1=(l_1,m_1,u_1)$ is estimated as follows:

$$V(M_2 > M_1) = Sub_{y>x}[\min(\mu_{M_1}(x), \mu_{M_2}(y))] \quad (7)$$

The equation can be equivalently written as:

$$V(M_2 > M_1) = hgt(M_2 \cap M_1) = \mu_{M_2}(d)] \quad (8)$$

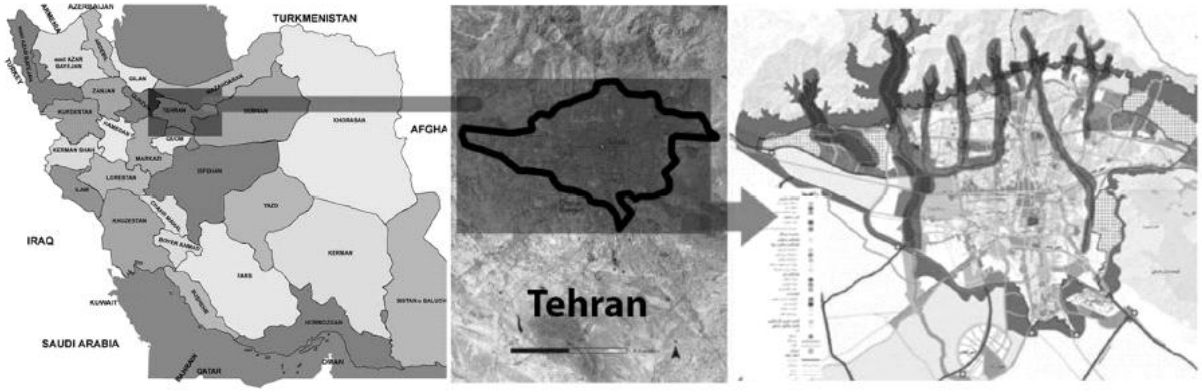

Fig. 1. Tehran Satellite Image and Northern River Valleys (Authors based on Tehran Master Plan, 2015)

Where d is the ordinate of the highest intersection between two membership functions μ_{M_1} and μ_{M_2} (Fig.2). To compare M_1 and M_2, we need both the values of V ($M_1 e \geq M_2$) and V ($M_2 e \geq M_1$).

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers (M_i ;i = 1,2,…,k) can be defined by:

Step7. Via normalization, normalized weight vectors are calculated.

These weights are non- fuzzy and through repeating the whole calculations, the weights of all matrices are obtained.

Step8. Combination of weights: final weights can be achieved by summing the weights of alternatives and criteria.

Gogus and Boucher (1998) suggested conditions for a rational ordering and illustrate that the irrational ordering is the result of relative preferences provided by the decision makers. They provided a test for consistency that will insure a rational ordering of the normalized weights. To do so and in assessing the consistency of judgments (15 experts)each matrix is derived and its consistency is calculated according to Saati's method. Calculating the consistency index by following equations:

Calculating the consistency ration (CR) by dividing consistency index on random consistency index. The C.R. should be under 0.1 to accept the matrice as reliable and consistent. The main idea is that the CR is a normalized value since it is divided by an arithmetic mean of random matrices consistency indices. If only was larger than 0.1, the decision maker revises just the mean values of fuzzy judgments (Tzeng, 2011; Zhang et al.2013).After prioritizing the contributing factors to restoration of river valleys in north of Tehran, they were applied in ArcGIS software to illustrate the numerical results graphically.

RESULTS & DISCUSSION

Structure of FAHP employed in the research is shown in the fig. 3. The restoration and reclamation of river valleys is the function of four factors: environmental, urban-spatial, cultural-social, and political-economic factors. The environmental factors consist of hydrology, vegetation cover, and microclimate criteria. The urban-spatial factors include urban infrastructures, accessibility and influential surroundings. Collective memory(mind) and public participation are components of cultural-social factors; and finally political-economic factors are depending on distribution of resources, and attracting those economic resources. Hierarchical structure of decision making therefore is shaped to assess the relative importance of factors influential in enhancement of urban river valley landscape and hence helping the biodiversity and ecosystem services towards urban sustainability (Fig. 3).

$$d(M) = V(M \geq M_1, M_2, .., M_k) = V[(M \geq M_1), (M \geq M_2), .., (M \geq M_k)] = \min V(M \geq M_1), \quad i = 1,2, \dots, k \qquad (9)$$

$$W = \left[\frac{d'(A_1)}{\sum_{i=1}^{n} d'(A_i)}, \frac{d'(A_2)}{\sum_{i=1}^{n} d'(A_i)}, \dots, \frac{d'(A_n)}{\sum_{i=1}^{n} d'(A_n)}\right] \qquad (10)$$

$$U_i = \sum_{j=1}^{n} w_i r_{ij} \qquad (11)$$

$$CR^g = \frac{(a^g_{\max} - n)}{(n-1)} \quad \text{and} \quad CR^m = \frac{(a^m_{\max} - n)}{(n-1)} \qquad (12)$$

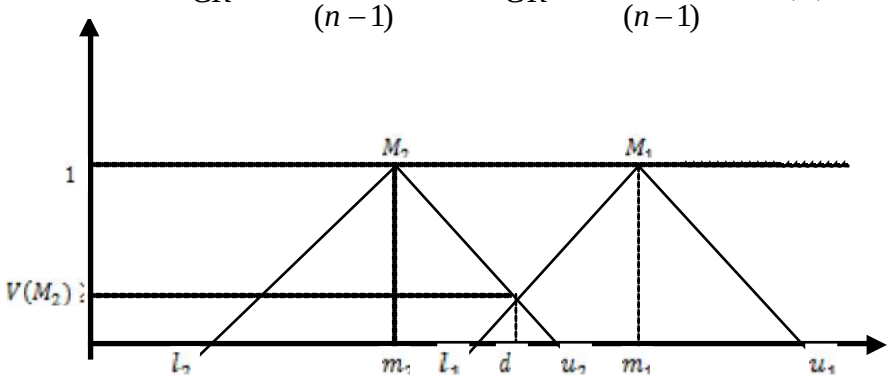

Fig. 2. Priority of two triangular fuzzy numbers

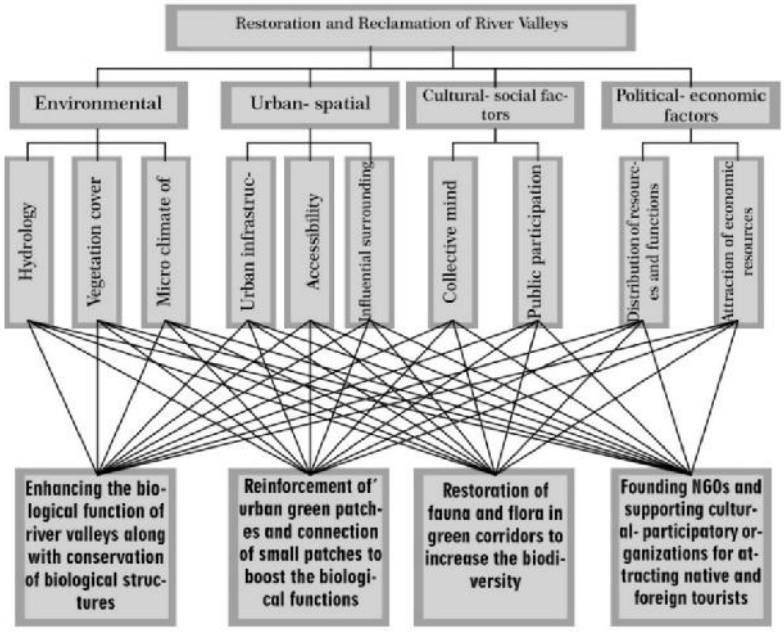

Fig. 3. The hierarchical structure of decision making

Steps 2, 3, 4: following linguistic terms were utilized for pair wise comparison. Alternatives and their abbreviated forms are presented in Table 2.

The Table 2, 3 and 4 present the arithmetic mean of experts' judgments. The sum of each row is calculated in the last column. According to the above mentioned results, priority of sub- criteria in comparison to contributing factors in river valleys restoration in Tehran can be summarized in Tables3, 4 and 5. Calculating the final weights of criteria, sub- criteria and alternatives shown in Tables 6, 7 and 8:

Table 2. Alternatives and their symbols

Option	Symbol
Enhancing the biological function of river valleys along with conservation of biological structures	A1
Reinforcement of urban green patchs and connection of small patches to boost the biological functions	A2
Founding NGOs and supporting cultural-participatory organizations for attracting native and foreign tourists	A3
Restoration of fauna and flora in green corridors to increase the biodiversity	A4

Table 3. The mean of pair wise comparisons regarding the rank of contributing factors to restoration of river valleys in Tehran

Criteria	Environmental structure	Urban-spatial	Cultural-social	Political-economic	Total	Normalized
Environmental structure	(1,1,1)	(0.68,1.333,2.2)	(1.32,2.333,3.4)	(1.72,3.533,5.4)	(4.72,8.199,12)	(0.128,0.321,0.745)
Urban-spatial	(0.76,1.6,2.6)	(1,1,1)	(1.36,2.4,3.6)	(1.92,3.333,4.8)	(5.04,8.333,12)	(0.137,0.326,0.745)
Cultural- social	(0.589,0.84,1.267)	(0.585,1.23,2.053)	(1,1,1)	(1.92,2.933,4)	(4.094,6.007,8.32)	(0.111,0.235,0.517)
Political-economic	(0.257,0.547,1.133)	(0.414,0.674,1.12)	(0.577,0.815,1.173)	(1,1,1)	(2.248,3.036,4.426)	(0.061,0.119,0.275)
Total					(16.102,25.575,36.746)	
		CR^m = 0.044		CR^g= 0.081		

Table 4.Weight and rank of the preference for sub- criteria

Criteria	Sub- criteria	Weight	Rank
Environmental structure	Hydrology	0.292	3
	Vegetation cover	0341	2
	Micro climate	0.364	1
Urban-spatial	Urban infrastructures	0.488	1
	Accessibility	0.368	2
	Influential surroundings	0.144	3
Cultural- social	Collective mind	0.544	1
	Public participation	0.456	2
Political- economic	Distribution of resources and functions	0.479	2
	Attraction of economic resources	0.521	1

Table 5. Weight and rank of the preference for alternatives regarding sub- criteria

Sub- criteria	Alternative	Normalized	Rank	Sub- criteria	Alternative	Normalized	Rank
Hydrology	A1	0.421	2	Influential surroundings	A1	0.267	2
	A2	0.486	1		A2	0.272	1
	A3	0.075	3		A3	0.199	4
	A4	0.019	4		A4	0.261	3
Vegetation cover	A1	0.47	1	Collective mind	A1	0.143	3
	A2	0.43	2		A2	0.116	4
	A3	0.1	3		A3	0.325	2
	A4	0	4		A4	0.416	1
Micro climate	A1	0.435	1	Public participation	A1	0	4
	A2	0.435	2		A2	0.045	3
	A3	0.089	3		A3	0.39	2
	A4	0.041	4		A4	0.566	1
Urban infrastructures	A1	0.325	2	Distribution of resources and functions	A1	0.039	3
	A2	0.342	1		A2	0	4
	A3	0.174	3		A3	0.385	2
	A4	0.159	4		A4	0.575	1
Accessibility	A1	0.274	2	Attraction of economic resources	A1	0	3
	A2	0.27	1		A2	0	4
	A3	0.22	4		A3	0.362	2
	A4	0.236	3		A4	0.638	1

Table 6. Final weight of Criteria

Criteria	Final weight
Environmental structure	0.313
Urban-spatial	0.31
Cultural- social	0.252
Political- economic	0.125
Sum	1

Table 7. Final weight of Sub- criteria

Sub- criteria	Final weight
Hydrology	0.115
Vegetation cover	0.153
Micro climate	0.137
Urban infrastructures	0.115
Accessibility	0.114
Influential surroundings	0.106
Collective mind	0.065
Public participation	0.09
Distribution of resources and functions	0.06
Attraction of economic resources	0.045
Sum	1

Table 8. Final weight of Alternative

Alternative	Final weight
A1	0.252
A2	0.255
A3	0.224
A4	0.268
Sum	1

According to the analyses, main criteria were classified in terms of:1) Environmental structure. 2) Urban- spatial structure. 3)Socio-cultural factors. 4)Political- economic factors;

Taking the results of rankings into account, environmental structure of river valleys is given the greatest importance, which implies the necessity of restorations according to the historic characteristics and their surrounding nature, so that fresh and clean air, will be directed again toward center of Tehran through a biologic filter. However, other criteria should be examined for proper function of the measures.

According to the findings of this research, sub- criteria can be prioritized and ordered as followings(digit1 indicates the top priority):

1. Vegetation cover
2. Micro climate of river valley
3. Urban infrastructures
4. Hydrology
5. Accessibility
6. Influential surrounding
7. Public participation
8. Collective mind(memory
9. Distribution of functions and resources
10. Attracting the economic resources

As can be seen, vegetation cover has the highest priority among restoration sub- criteria. Micro climate, urban infrastructures and hydrology are respectively of higher importance too. Hence, designed structure for restoration of river valleys and also executive policies should be based on priority of sub- criteria and adaptability to environment.

Finally, recommended alternatives were ranked and analyzed; the result is as below:

1. Enhancing the biological function of river valleys along with conservation of biological structures.
2. Reinforcement of' urban green patches and connection of small patches to boost the biological functions.

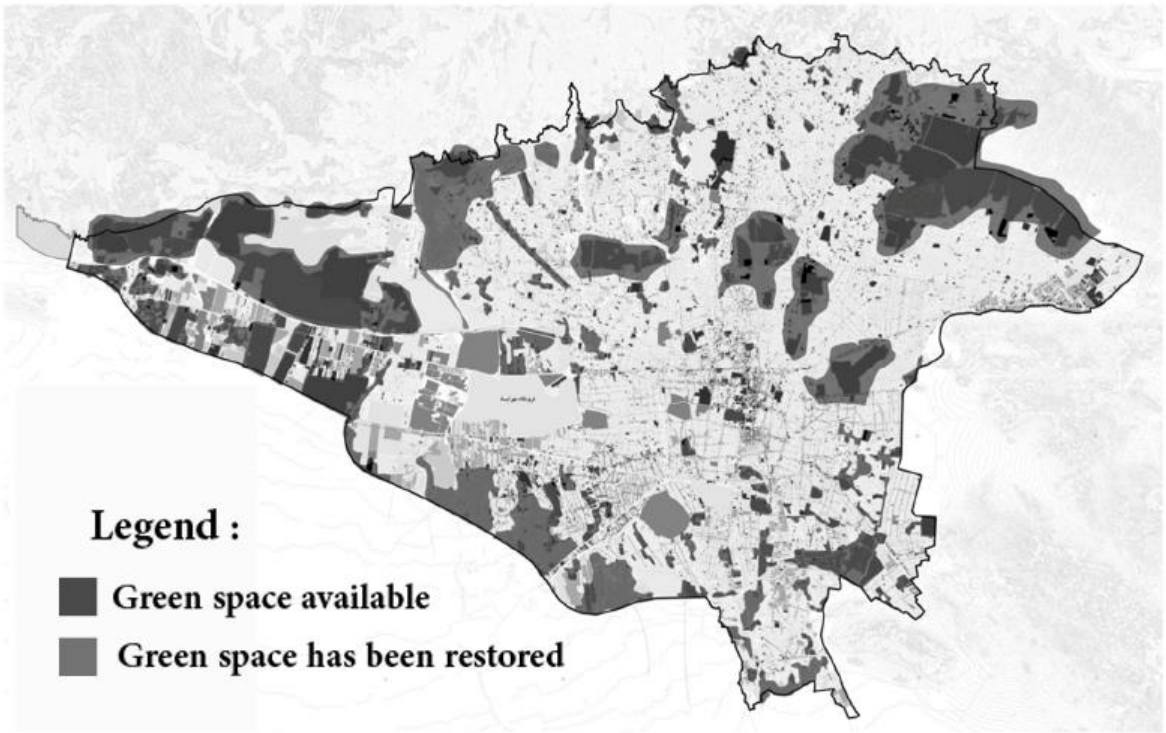

Fig. 4. Connecting fine patches to create larger biological patches

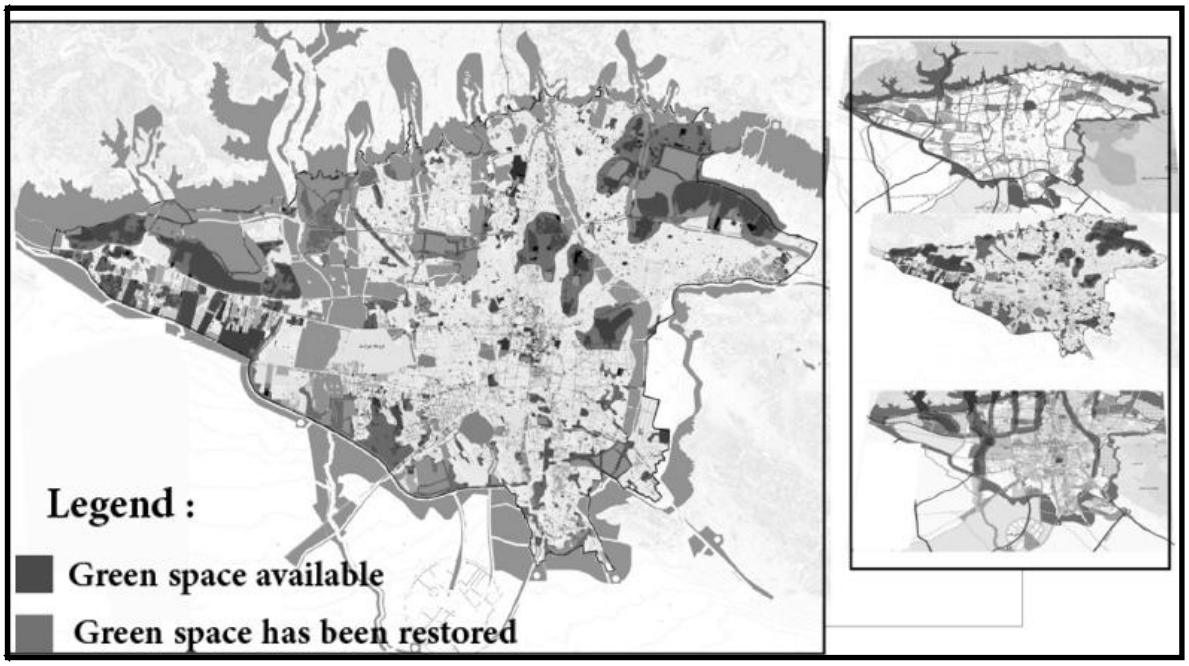

Fig. 5. Overlaying the analytic layers of urban greenbelt, developed patches and river valleys to determine the developed structure of Tehran Metropolis

3. Founding NGOs and supporting cultural-participatory organizations for attracting local and foreign tourists.
4. Restoration of fauna and flora in green corridors to increase the biodiversity.

Findings of the research show that alternative one "enhancing the biological function of river valleys" has the highest priority according to the experts` judgments; hence, it should be supported through conservation of biological structures. At the next stage, urban green patches need to be restored and connected to other largerpatches which finally lead to higher ecological potentials. Moreover, public participation and founding NGOs facilitate to achieve the goals set for restoration of river valleys. All measures will finally result in fauna and flora restoration and increase in biodiversity richness in river valleys of Tehran(Fig 4, 5).

CONCLUSION

According to the field survey and observation, data collection and landscape analyses, relevant literature review, the results of FAHP method and also compatible to study area's natural setting, the following strategies are derived to restore and reinforce ecological functions:

a) Connecting the garden patches to prevent their fragmentation and improving connectedness and sustainability of green patches.

b)Connecting the vegetation cover patches (such as urban green spaces) to boost their ecological values and creating ecological network; and creating a green buffer zoneon river banks so that natural corridors and their vicinity is preserved and also construction on the buffer zone will be limited.

c) Preservation of natural bed of the river and reclamation of destroyed areas in order to protect the natural characteristics, this should be done with the help of planting indigenous vegetation species for stabilizing the river banks and landscape design.

d) Taking the ecological needs of living organism (e.g. plants) into consideration during landscape design and planning through having the least disturbance on natural sections of river valleys.

e) Utilizing native material and elements for ecological design in order to conserve the harmony with intact nature, and helping the nature be integrated more into the residential areas.

f) Controlling floods and water flow in flood- prone locations through preventing the remnant parts of the river form turning into concrete canals. And finally, the restriction of the construction density in the vicinity of rivers through preventing sewage and waste water release into river.

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