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Improving the Natural and Built Ecological Systems in an Urban Environment

Aminzadeh, B.[1*] and Khansefid, M.[2]

[1] Faculty of Urban Planning, College of Fine Arts, University of Tehran, Tehran, Iran
[2]Department of Environmental Design, Graduate Faculty of Environment, University of Tehran, Tehran, Iran

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ABSTRACT: This study investigates the application of landscape ecology in planning and design of urban ecological systems. The ecological approach to landscape planning and the concepts of designing and implementing ecological systems have gained increasing attention in the last two decades. However, the ecological systems of urban environment need more research to consider built and natural patches and corridors together and to provide proper and applicable strategies that meet all of the diverse aspects of planning and designing sustainable urban systems. This approach could help in defining sustainable landscape development, aiming for a balance between both physical and natural systems in urban areas. This research is focused on Tehran's metropolitan area as a case study to provide a relationship between landscape ecology and urban planning and design to propose a model for analyzing and providing strategies and policies for conserving and resorting urban ecological systems. The spatial structure of green and natural areas are studied and categorized based on the patch-corridor-matrix model. Overlaying the selected layers helped provide strategies for conservation and reclamation, and policies to improve the structure and function of urban landscapes. The strategies to restore the ecological structure and to develop its function in Tehran metropolitan area are based on structural congruence, aggregate with outliers, local compensation and indispensable patterns.

Key words: Ecology, Landscape, Natural, Built, Systems, Tehran

INTRODUCTION

In the recent years ample attention is paid to the ecological system in urban areas (Aminzadeh & Ghorashi, 2007; Bahraini & Aminzadeh, 2007; Micarelli, *et al.,* 2007; Vahadj *et al.,* 2007; Yavari, *et al.*, 2007; Micarelli & Pizzioli, 2008). System refers to a regularly interacting or interdependent group of items forming a unified whole, a group of interacting bodies under the influence of related forces, an organized or established procedure and harmonious arrangement or pattern. These meanings provide a good basis to use the term system for a more holistic approach towards urban environment. The urban ecological systems can bridge the conflict between reserve conservation, fixing nature in space and time and development. They help to focus on an effective spatial scale as well. As the coherence of an ecological system is based on ecological processes it may be single purpose or multipurpose (Jongman, 1995). The multi-objective systems goes beyond ecological improvements of the city and habitat needs of wildlife, to address recreation and beautification, promoting urban flood damage reduction, enhancing water quality and other urban infrastructure objectives. Extending the ecological system concept with multifunctional indicators is a promising step towards sustainable city. Ecological systems, as natural or built potentials, play a leading role in achieving sustainable urban environment. By focusing on structures, functions and transformations of the environment, landscape ecology approach is an attempt to find patterns and interrelations between landscape elements, built and

*Corresponding author E-mail: bgohar@ut.ac.ir

natural patches, corridors and the matrix (Forman, 1995; Ingegnoli, 2002). Ideas such as urban open space network (Turner, 1995; Cranz & Boland, 2004), park systems (Jongman & Pungetti, 2004; Maruani & Cohen, 2007) and greenway networks (McHarg, 1969; Ahern, 1995; Little, 1999; Fabos, 2004; Turner, 2006) are developed as initiatives to interweave the natural and built systems in ecological landscape design and planning (Makhzoumi & Pungetti, 1999). Urban environmental quality and the landscape structure of Tehran metropolitan area and utilizing natural river valley corridors for ecological restoration of urban environment in landscape scale and other ecological features were studied to improve the ecological structure (Yavari *et al.*, 2007) and consequently mitigating some of the environmental constraints the city encounters in an increasing rate. Based on the literature reviewed , the main objectives of this study are 1) to apply landscape ecology approach as could be interpreted in urban ecological planning, 2) to determine the current situation and analyze the natural and built elements of the ecological systems of Tehran which faces numerous environmental problems and pollutions due to its rapid growth, 3) to suggest strategies for structural and functional improvement of natural and built urban ecological systems of the case under study, and 4) to propose a model for the application of ecology in landscape scale.

In addition to the theoretical bases based on landscape ecology, the below experiences are helpful to develop an ecological framework for improving the ecological systems in Tehran metropolitan area (Table 1).

Adopting a new ecological view of the metropolitan landscape in designing New York greenspace system (Flores *et al.*, 1998) suggests a framework that emphasizes a dynamic view of a biologically rich urban environment with a focus on interactions among multiple sites across temporal scales. This approach is defined by presenting five key ecological principles as follows:

a) Content: a wide spectrum of ecosystem functions that are strongly linked to ecosystem structure

b) Context: a combination of localities that results in considerable variability in the kind of ecological context specific to each site

c) Dynamics: suggests that with structural changes, ecosystem function also changes

d) Heterogeneity: means ecosystems need not be pristine, only flexible, connected, and diverse with complement of species to generate the genetic, biological, and biogeochemical capacity to adapt and respond to a changing environment

e) Hierarchy: help manage ecological complexity by organizing it into discrete functional components operating at different scales

The application of these principles resulted in creating regional water reserves that provide the region with fresh drinking water, protecting harbor (the area's most significant ecosystem), and delimiting the outward expansion of the region's urbanized core. Establishing large regional reserves should be of a sufficient size to withstand the impact of different disturbances without disrupting its main functions. A full-scale reinvestment in urban parks, public spaces and natural resources to improve the environmental quality of our cities, provide a fair share of park land to urban residents, and help cities attract businesses and residents.

Comprehensive concept plan of urban greening based on ecological principles, a case study in Beijing, China (Li *et al.*, 2005) attempts to answer how to establish an urban greening plan at the regional, city and neighborhood levels to achieve long-term sustainability. This three-level system constitutes an integrated ecological network for urban sustainable development of Beijing. For future development of the city, urban parks, forestry, agriculture, water and infrastructure should be planned and designed in an integrated way. It has the prospect of achieving the long-term goal of developing Beijing towards an Eco-City. Ecological principles and requirements for urban greening of Beijing define the temporal and spatial scale of greenspace planning. Three spatial scales have to be considered. At the regional scale, the entire area of Beijing Province is considered. Even the relationship to the neighbor-city Tianjin is included in the plan. At the city scale, the urban area of Beijing with its suburbs and the surrounding peri-urban zone is taken into account, and at the neighborhood scale, some selected and typical areas within the fourth ring road are

Table1. The natural and built ecological systems in 3 metropolitan areas

Region	Ecological Principles	Strategies
New York	content	creating regional reserves
(Flores et al., 1998)	context	invigorating green spaces in highly urbanized
	dynamics	environmentscreating a regional network of green spaces
	heterogeneity	
	hierarchy	
Beijing	spatial scales	integrating isolated greenspace into a network clarity and
(Li et al., 2005)	time-scales	consistency of greenspace system enhance ecosystem
		services
		bridge separating elements
London	connectivity	creating networks of open space and ecological corridors
(Turner, 1995)	connectedness	establish networks of ecological space, greenways and
		parkways

considered.The plan distinguishes between three time-scales for implementation. The ecological principles and requirements for the urban greening in Beijing are as follows:

a) Structure and function: changing the function of fragmented and isolated greenspace

b) Clarity and consistency: an easily-communicable long-term vision and an integrated greenspace

c) Functional and ecological diversity: combining several ecological functions and are not monofunctional

d) Biodiversity and eco-services: enhancing ecosystem services by high greenspace quality and diversity and improve specific conditions for endangered species

e) Distribution of greenspace: creating public parks close to high-density residential areas and no pollution in fresh air-generation zones and fresh air corridors, establishing big forest areas and ecological buffer belts at the regional scale and vertical greening for high-density settlement

f) General acceptance and implementation of the plan: publicizing the concept through the media, involving decision makers and the public as a strong driving force to promote green space development.

Emphasis has been placed on planning vegetated urban fields in London. Other types of green space have been neglected (Turner, 1995). This attempt has distracted planners' attention from the vital task of creating networks of environmentally pleasant open spaces. The only continuous ecological corridors in London are the rivers, which constitute another layer to the Green Strategy. As London is conceived to have webs of public open space, it would have been possible to plan for more diverse habitats and natural processes. The greenway theory and parkways are introduced as parts of this ecological system and urban rivers are converted into blue-ways, by opening up access to the banks of rivers. Ecoways are established networks of ecological space in cities by using and merging urban water courses, public utility corridors, parklands and private gardens into a single integrated system of ecologically important components.

Urban ecological systems can link terrestrial ecological, physical, and socioeconomic components of metropolitan areas (Pickett *et al.*, 2001) in an ecological approach to landscape planning (Sanderson & Harris, 2000; Steiner, 2000) in urban environment. The experiences and theories demonstrate that ecological patches and corridors play a crucial role in the sustainability of urban

Table 2. Considerations for structural and functional improvement of patches, corridors and matrix in the urban landscape context

		Improvement considerations for patches, corridors and matrix in the urban landscape context
Patch	1	Large patches Protecting large patches with high ecological value amid the urban built environment often surrounded by other conflicting land uses
	2	Small patches Integrating the small patches for better functioning of the ecological systems especially in densely built-up and populated areas
	3	More patches Making more patches for facilitate the penetration of the ecological flows into the urban fabric
	4	Patches vicinity Creating close patches for increasing their ecological functions, more convenient and less obstructed flows between the patches
Corridor	5	Corridors Connectivity Connectivity of the corridors will benefit the individual and overall ecological functions of them
	6	Corridors branching patterns The interwoven structural pattern of both branching natural or circuit built corridors in their hierarchical order and their interactions directly influence their ecological functions
	7	Patches and corridors Connecting patches through natural or manmade corridors for higher ecological performance
Matrix	8	Integrity Interconnections betweens the ecological patches and corridors in the urban natural and built matrix to enhance and protect integrity of the city and ecological flows
	9	Regional perspective Considering the ecological systems beyond the city limits where the ecological flows are continued or originated

environments and their transformations directly influence the ecological functions of the city. Some general points for structural and functional improvement of patches and corridors in the urban context are categorized in Table 2.

The application of landscape ecology in improving urban ecological systems based on patch-corridor-matrix model depends on the local and regional ecological conditions. The case of Tehran metropolitan area will help to recognize the natural and built systems' potentials and restrictions and the ways by which the urban ecological structure and function could be improved.

MATERIALS & METHODS

The data required for the research has been gathered from Tehran planning organizations and prior researches, reports and plans, satellite images and aerial photos regarding the city natural and urban context. The data has been analyzed based on patch-corridor-matrix model to come to the ecological structure of the city.

The environmental potentials and restrictions of the natural and built ecological systems are fol-

lowed by considerations and suggestions for structural and functional improvement of urban ecological systems in Tehran metropolitan area.

The base layers of data maps are overlaid to analyze the overall ecological structure and function of the city, natural and built patches including open and green spaces, due to their fundamental role in the ecological structure of the city are recognized. Hydrological networks are studied as main ecological corridors in the urban landscape context which vary from natural river valleys to manmade surface or subsurface water flows. The main hydrological corridors influence energy, air and nutrients flow through the city. Main access of roads, highways and streets as main structural elements and ecological corridors in urban context, especially in the densely built up urban fabric, as connecting elements of the ecological patches and as structural elements of the ecological systems. The three mentioned layers have been analyzed to locate the main and most effective ecological patches and corridors in the city matrix. The overall ecological structure of the city is then obtained by merging the layers of natural or manmade ecological patches and corridors into one single map which contains all the effective features in the structure of the city (Fig.1).

The main effective element in the ecological structure and function of Tehran are natural and built patches, corridors and matrix.The abundant lands, remnant natural patches, the existing hills and high lands are located in central and south-east Tehran. Where the micro climatic conditions allow, these patches are covered by bushes, low shrubs and dispersed trees. The natural patches are under constant pressure of urban development (Fig.2).

The urban forests, parks, gardens, orchards and other built green areas in all shapes and sizes with interrelations with the whole landscape elements are named as built patches. They vary according to their sizes; two large urban forests in east and west side of the city are the main built patches with high ecological functions, small built patches of urban parks are scattered in the urban fabric.The seven river valleys, north-south, are characteristic of natural corridors of Tehran landscape structure. They are fertile habitats that support a variety of flora and fauna and play a significant role as catchments and a place for energy and winds flows to remove air pollutions from the city environment, providing opportunity of connectedness with the natural upland-lowland natural context.

The natural hydrological corridors along the river valleys face more destructing factors and have less ecological functions from north to south because of their structural modifications (Fig.3). The natural corridors connect many natural or built patches that are scattered along them. The natural corridors are mostly oriented toward north-south. The east-west ecological connections are restricted due to morphological structure of city. Built corridors include linear parks along the river valleys, roads and highways and their boundaries, parts of the city greenbelt, tree lines along avenues, canals and gutters and subterranean hydrological flows of Quanats. The built corridors follow the hierarchy dictated by the main roads which are oriented toward east-west. Natural-built matrix is the most dominant element of the Tehran landscape which varies from natural mountainous to the urban context, then the patches of nature in the centre and finally the agricultural landscape and the desert edge in the south.

RESULTS & DISCUSSION

The overlaid map illustrates both natural and built structural elements of Tehran ecological systems, the main constrains in Tehran ecological context is land use change, the invasion of urban development to the remnant patches of nature, the destruction and obstruction of the natural river valley corridors, and the gradual separation of urban fabric and green areas as a result of the disregarding urban ecological flows and processes and lack of comprehensiveness in developmental plans.

The remnant natural and manmade ecological patches are under constant pressure of urban development due to scarcity of land in the increasingly heavily built-up metropolitan area. Some of them most important ecological patches such as large remnant natural patches in the center, large patches of built urban forests in the east and west and the natural corridors of the seven north-south river valleys and their hydrological flows which

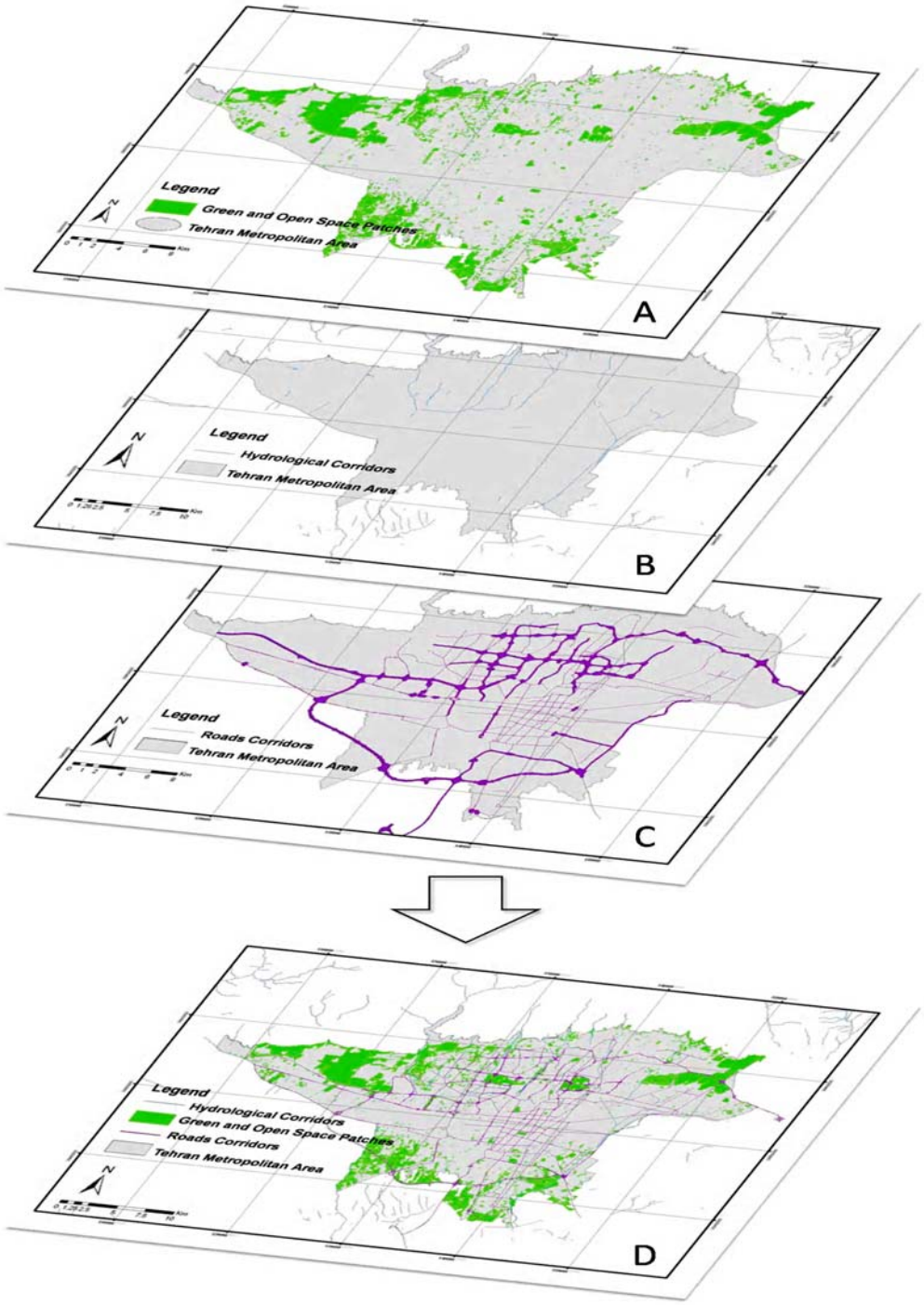

Fig. 1. overall ecological structure of Tehran

(A) The green and open space patches as main manmade or natural ecological patches
(B) The hydrological corridors as main natural ecological corridors
(C) The main access of roads, highways and streets as main manmade ecological corridors
(D) The existing ecological patches and corridors in the manmade-natural matrix of Tehran forming the ecological structure of the city

Fig. 2. The green patches as main manmade or natural ecological patches, under constant fragmentation and destruction pressure of construction and urban development

Fig. 3. The river valleys as main natural ecological corridors, fragmented, obstructed or transformed to drainage canals

have been already fragmented by transportation corridors or disturbed by urban development and other changes in land use.

As Fig.4 shows remnant natural patches in the middle(a), manmade forests in the east(b), the remnant mountains of south east(c), the manmade patches of green amid the urban matrix(d), highways and roads as main manmade corridors in the urban matrix(e), agricultural lands in the south, south east and south west(f), manmade forests in the west(g), the river valleys as main natural corridors(h), and mountainous lands in the north as the natural matrix(i), are the most important natural and built elements of Tehran ecological systems.

To establish, enhance and complete the ecological networks in Tehran, the city faces some restrictions and posses some potentials both created by natural environment or caused by human activities and the built environment which have been classified by the source of initiation. The natural and built potentials and restrictions of Tehran ecological systems are described below.Natural Potentials include the river valleys facilitating upland-lowland flows and make connections north-south, natural uplands in the north,

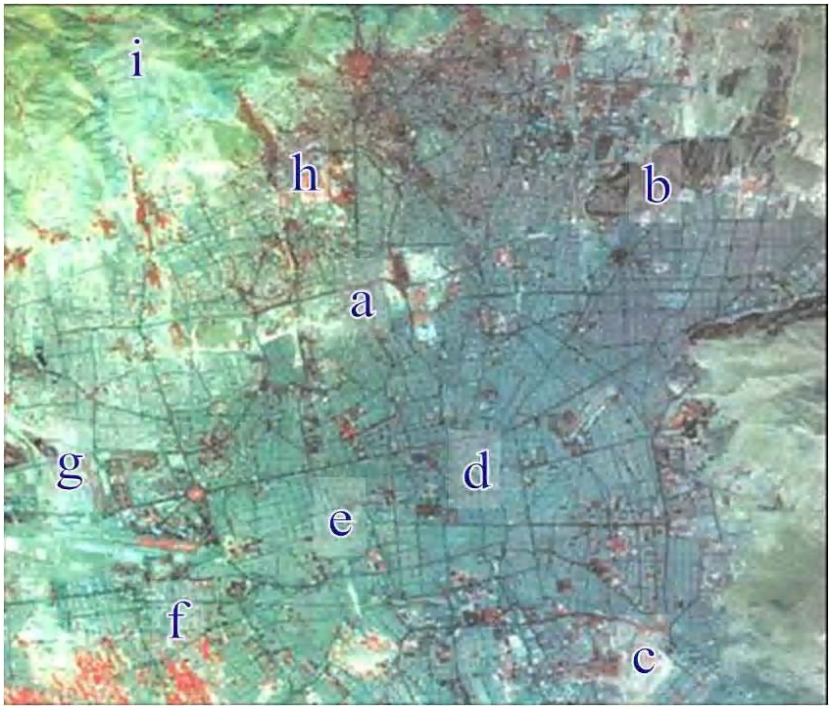

Fig. 4. Natural and built elements of Tehran ecological structure

north, east and south-east, the remnant natural patches in the north and the middle of the city, the natural hydrological flows as hierarchical natural structures.

Built Potentials consist of highways and roads as main network and connecting elements between the patches east-west, the patches of built green areas scattered among the built-up areas, the built hydrological flows along main roads, highways and streets.Natural Restrictions include the high and steep lands in the north and east with limited water supplies and soil depth as restrictions to establish patches of ecological functions and the dry climatic conditions.

Built Restrictions consist of the densely populated urban areas make penetration of ecological corridors into these areas difficult, the destruction of ecological networks especially along the river valleys and the natural hydrological flows**,** fragmented built patches and pollutions and their detrimental effects on living conditions.The main principles to restore the ecological structure and to develop its function in Tehran metropolitan area are structural congruence, aggregate with outliers, local compensation and indispensable patterns which are described below.

It signifies that transformations should not cancel the spatial relationships between geomorphology, vegetation, hydrology and land uses. Creating an integrated system of major natural corridors and patches within and outside the city, connecting the built green patches in the heavily built-up urban context such as parks and other green patches and improving the ecological features citywide will help the integrity of natural and built systems by establishing dynamically stable ecological systems or networks in poor vegetation conditions of river banks and hills and steeps next to the highways to providing the basis for the natural systems to thrive and flourish usually regarded as naturalization of urban ecological systems.

Land containing humans is best arranged ecologically by aggregating land uses, yet maintaining small patches and corridors of nature throughout developed areas, as well as outliers of human activity spatially arranged along major boundaries. Preserving the large remnant natural patches and creating urban forests in the hilly land will help to arrange the structural elements of Tehran ecological network in a more sustainable way. Creating a new system that did not formerly exist and producing ecosystems in connection to existing

hydrology and morphology which will include interruptions in manmade patches and corridors with high ecological values in densely built-up and populated areas in the city centre and enhancing the activities undertaken to improve existing environmental quality at some places with limited water supplies or other constraining factors such as dry uplands or land with poor drainage conditions.

Serious transformations which alter many characters of a landscape have to be compensated through an ecologically balanced therapy inside the same unit. Regarding the existing hierarchy of ecological patches and corridors in the urban context, the urban green infrastructure, and following natural rules will help the local compensation. Naturalization of river banks, reclamation the disturbed or obstructed natural patches or corridors in the urban or suburban environment to meet the recreational needs of the citizens and the ecological needs of the city, providing water supplies to establish vegetation in a specific area lacking water such as dry upland areas in Tehran greenbelt, and constructing new parks, water features and ponds, greenways and establishing park systems will benefit the local and regional compensation in Tehran ecological systems.

Ecological rehabilitation or partial recovery of ecosystem, not necessarily reestablish the pre-disturbance structure where alterations in natural and built patches and corridors are seen. Mitigating defined as site restoration to an environmentally and socially acceptable condition, but not necessarily natural, for drainage problems in the south because of the low-land situation, water pollutions and sewage disposal. Reclamation or series of activities intended to change the biophysical capacity of an ecosystem in the disturbed or obstructed natural patches or corridors in the urban or suburban environment face severe adverse transformations.

It is necessary to leave wider possibility of connections and fluxes regarding the whole landscape, especially top-priority patterns and those which are more sensitive to the surrounding environment. Preserving large remnant patches and large green patches in the urban fabric, preserving the upland mountainous and lowland agricultural land from development and using them as connectors to ecosystems beyond the city boundaries through establishment of dynamic ecological systems or networks could help in unify the ecosystems within and outside city.

CONCLUSION

The process to provide a model for urban ecological systems based on landscape ecology approach should take all natural and built structural elements into consideration. The process of improving the ecological systems is illustrated in Fig.5.

The remnant natural patches and corridors in the urban environment are to be preserved and restored to increase their ecological functions of the city so that the natural flows can continue and penetrate into the built environment. The built patches and corridors within the urban context can act as main elements to make an ecologically functional system. The built patches are most influential factor in the densely built-up and populated city regions, and the built corridors can act as main connecting elements between the natural and built patches. Protecting the integrity between structural elements, preserving the original pattern of ecological systems, will help to establish and enhance the ecological processes and flows in the urban and suburban environment.

The built and natural ecological features of Tehran do not seem to have complementary interaction and urban development in many cases has led to destruction or obstruction of ecological flows of natural corridors in the city context. The river valley corridors and remnant natural patches in the middle and built green patches in the east and west are considered as main structural elements in Tehran urban ecological system. Categorizing the building elements of the ecological structure of the city into natural and built with landscape ecology approach and patch-corridor-matrix model will help to clarify the current situation and classify future improvement policies and activities.

Based on suggestions for structural and functional improvements of the Tehran ecological systems and the major problems that the city faces, some of the activities for improving Tehran ecological systems are as follows.

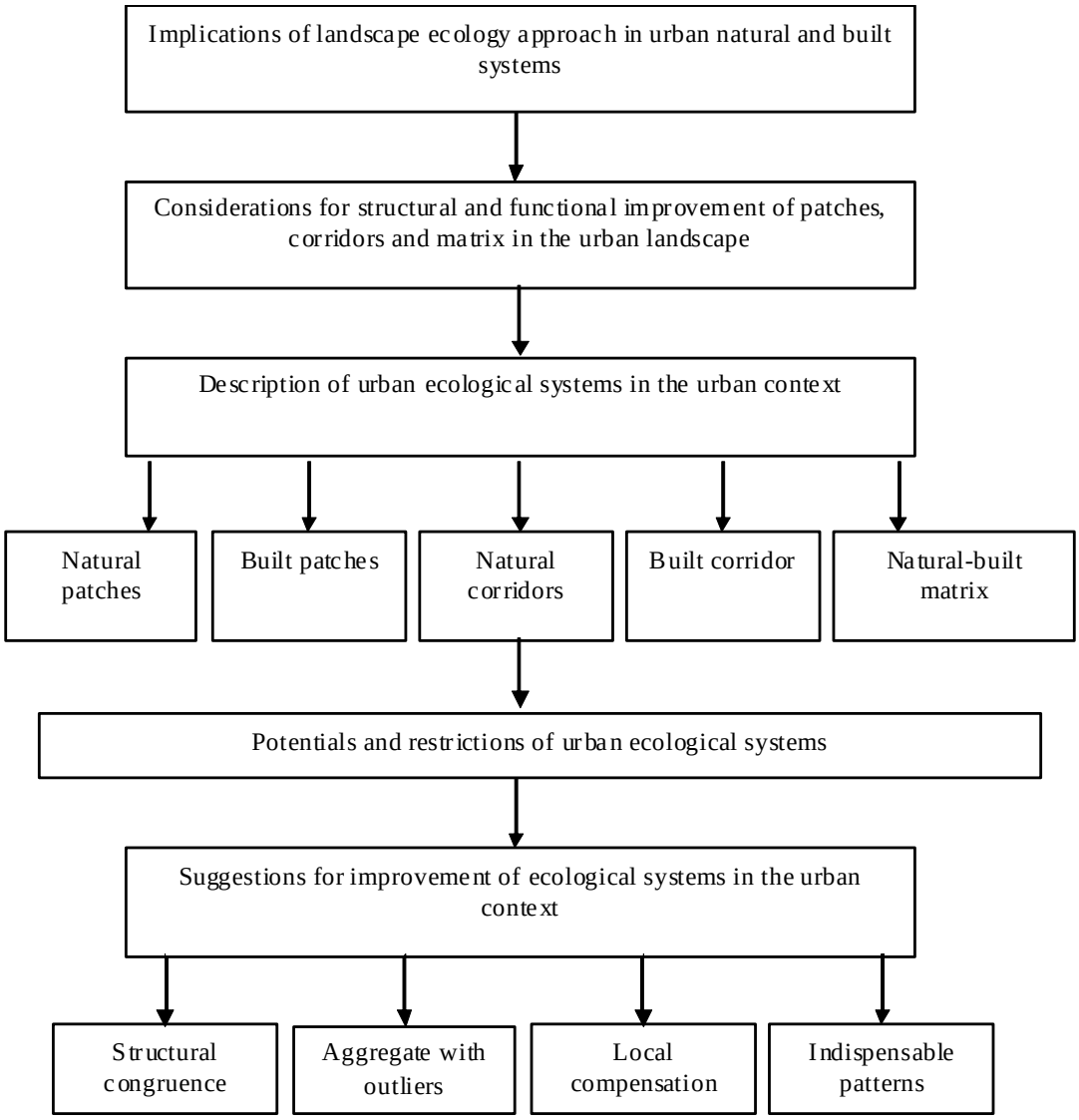

Fig. 5. The process for improving the natural and built ecological systems in the urban environment based on landscape ecology approach

a)Restoring the natural form and structure of the river valleys, natural matrix connectivity, and sensitive built areas such as roads crossing the river valleys.

b)Cultivating vegetation and penetration of the natural and built ecological patches and corridors into the urban fabric as ecological rehabilitation activities.

c)Improving rules and regulations against the alterations of ecologically important features for preservation purposes.

d)Removing the pollutants through physical, chemical and biological processes and assisting vegetation growth through bioremediation techniques to mitigate some of environmental problems.

e)Naturalizing the environment and optimizing the microclimatic conditions, providing the basis for the natural systems to thrive and flourish.

f)Creating new or ecologically important features such as small green patches in the urban fabric establishing greenways along main roads and a hierarchical system of linear parks in the urban context.

g)Providing water supplies to establish and enhance vegetation in specific areas such as dry upland and hilly lands in the center and providing better drainage in low-lands of the south.

h)Preparing suitable conditions in landfills in the suburban areas and the abandoned mine lands and forsaken industrial lands to reclaim the disturbed or obstructed natural patches or corridors.

The contributions of ecological systems will directly modify landscape elements in form and consequently improve them in ecological functions. The ecological systems in the urban context will act as main supporting features to achieve and ensure dynamism and sustainability in the city. The application of landscape ecology approach as interpreted in urban ecological systems planning based on the current situation, description and analysis of the natural and built elements of the ecological features in Tehran metropolitan area and the suggested policy making issues and strategies for structural and functional improvement of urban ecological environment and the considerations for structural and functional improvement of patches, corridors and matrix in an urban context can be generalized but some of the policy making issues and strategies for improvement of urban ecological systems may vary or diversify according to local natural and manmade landscape elements and geomorphologic and hydrological varied conditions and the landscape structure of the constructing elements of the ecological features in the urban environment.

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