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Original Research Article

Analyzing and Developing Strategies for the Ecological Restoration of Urban Rivers in the Framework of Ecological Urbanism*

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Abstract | Nowadays, continuous urban development has disturbed the ecological conditions of cities by damaging the natural ecosystems within them. Inner city rivers which are natural ecosystems with ecological nature have an impact on the restoration of the ecological conditions of cities. The framework of ecological urbanism emphasizes the continuity of the ecological structures of natural ecosystems in cities and plans and formulates strategies for their restoration. This research, which is framed by ecological urbanism, focuses on restoring the ecosystem of urban rivers. This paper first examines the theoretical foundations of ecological urbanism, the ecological nature of rivers, the ecological damage caused by urban development, and the restoration of urban rivers. Then, it draws upon the analogical-inferential method to analyze reliable scientific sources, and the opinions of researchers, and then extracts components for the process-based ecological restoration of urban rivers. Based on the ecological components, it develops planning strategies on a macro and micro scale to rehabilitate and protect the ecosystem of rivers and their banks and adjacent lands, increase the flexibility of the river ecosystem in the face of future climate disturbances, and prevent human interference in natural processes. Recognizing the main causes of ecosystem destruction, protecting the health of the river, restoring the geomorphology of the river in the city, creating and connecting biological ecological networks, preventing the entry of sewage and polluted urban runoff, and controlling floods by maintaining the conditions of the river ecosystem, developing restoration plans and measures in accordance with urban development, changing people's attitudes toward protecting the river, and restricting the presence of citizens in the river's territory are strategies on a macro scale of planning and implementation. Such strategies are made possible by strategies on a micro-scale and can be used in urban development planning under similar conditions and result in ecological urban planning which is the future of contemporary cities.

Keywords | *Ecology, Ecological Restoration, Ecological Urbanism, Urban Rivers, Urban Development.*

Introduction| The industrial revolution brought a new method of converting energy and producing goods, setting man from his reliance on the environment. When humans began to build megacities, they caused substantial damage to the structures of flora and fauna, water and soil resources, and disrupted the ecosystems. The chaos of human native life has endangered the survival of man himself. Climate changes, the heat of the earth, and the environmental hazards of life on earth have made life on earth unfavorable for mankind, and as a result, in the future, there will be an ups and downs challenge between humans and the environment, which has been caused by the inappropriate activities of humans in dominating nature over the centuries. The environment is expected to change but not be destroyed. That is the reason why the way of dealing with the environment should be changed. In addition, the world's population is on the rise, and along with that, the continuous flow of migration from

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rural areas to urban areas is also increasing. This growth trend in many of these cities is so high that conventional planning methods cannot respond to their rapid and intense changes. The challenge of ecological urbanism is to find a way to respond to these conditions. Such strategies have a long history that began at the beginning of the 20th century with the activities of Louis Mumford , who is the author of the metropolitan theory and the substantive theory in urban geography (Mumford, 1961). He is a follower of Patrick Geddes, who suggested that the planning of big cities should be based on a humanitarian and nature-oriented (ecological) approach. Similar to this approach, "ecological urbanism" can create changes in the factors that are effective in the formation of the city, such as geography, orientation, weather, and pollution (Mostafavi, 2013). Urban ecology provides an opportunity to think about the wider social consequences of the environmental movement (community-environment connection) and possible long-term consequences for our understanding of cities (human-environment connection) (Hodson & Marvin, 2013). Urban ecology is a guide for city builders and urban planners to coordinate the direction of city movement and development with environmental programs, as well as to study the complex interactions between humans and their structures with organisms (natural factors) living in the city. Scientists who study the ecology of cities attempt to find the best solution for the integration of nature in cities (Moghadasi, 2016). Rivers are the unique geographical features of cities. Rivers are considered important factors in the location, formation, and expansion of cities, among the natural elements that have been with them since the beginning of the creation of cities, and as a result, they contribute to the skeleton and shape of cities. This is a feature of many major cities in Iran (Isfahan, Tabriz, and Shiraz) and around the world (London, Paris, and Los Angeles). Even though some rivers have not played a role in locating the core of the city, they have had an impact on the growth of the city. Protection and planning for the efficient and optimal use of water flows and seasonal rivers (especially in hot and dry regions) affect the water management of seasonal floods and the strengthening of underground water resources, especially rivers that are located on the banks or in the interior of the urban texture; they are changing from a natural and meandering form to a channelized and inflexible form. Since urban rivers are one of the geographical organisms of each land and affect its functioning, it is necessary to preserve and restore the ecological value of the rivers in each land through planning.

Research Questions

The realization of "restoration" of the natural structures of urban rivers is affected by the attention given to the components and criteria related to the ecological nature of rivers. To address the challenge of "restoring rivers based on their ecological nature," ecological urbanism is one approach that takes into account formed urban structures and nature in cities, particularly rivers. In this research, it is assumed that achieving components to restore the ecological nature of rivers will be an effective factor in the formation of the urban ecological structure. This can attract the attention of the city and urban planners. The goal is to restore the ecological nature of urban rivers as potential growth areas to improve biological quality in the city and urban ecological conditions. That leads to the formulation of strategies for the ecological restoration of urban rivers. It is also assumed that the planning and intervention along the river bank should be done in such a way that the morphological structure of the river is close to its natural meander structure so that the connection between the different parts of the river ecosystem and the urban system and surrounding lands is established, and the set of artificial systems (constructed by humans) and the natural systems (the river and the open and green spaces around it) can act as a supporting system for the ecological conditions of the city. The river ecosystem can be improved, and as a living urban organism, it affects the ecological conditions of the city. In this case, the city enters into a dynamic interaction between humans (citizens) and urban structures and urban nature, especially rivers, until ecological features are formed in urban development. This research seeks to answer the following questions:

- How can the ecosystem of urban rivers be restored to achieve ecological urbanism?
- With reference to ecological urbanism, what components can positively contribute to the ecological restoration of urban rivers?
- What strategies for the ecological restoration of the river ecosystem can contribute to the structure of urban development?

Research Method

In terms of goals, this research is applied-developmental. By relying on and using the cognitive context and information provided through basic research, this seeks to achieve practical development and a practical goal. The necessity of this research has been highlighted by the problem of the urban development projects in Iran regarding the urban natural environments and the lack of proper planning. This study attempts to find strategies to solve the problems of urban development in the face of inner-city rivers. In the first part, after reviewing the research literature, we presented the theoretical foundations of ecology, ecological urbanism, the ecological nature of urban rivers, the damage of urban development on the ecological structure of urban rivers, the concept of restoration, and ecological principles and strategies for restoring the ecosystem of urban rivers. Then, using the analogical-inferential method, we analyzed the studies from reliable scientific sources and scrutinized

the opinions of the researchers to extract the components of the ecological restoration of urban rivers. Then we presented strategies for dealing with inner city rivers in all seasons of the year (days of floods and periods of drought on a macro and micro scale (in the area of implementation) which can be used in urban planning and urban development plans to be known as living urban organisms. Certainly, the proposed results for each context should be specific and accurate and should be developed with regard to the features of that context same based on the practical and implementation framework.

Literature Review

Based on the research review literature, since the beginning of the 21st century, extensive studies have been conducted on ecological urbanism. The studies include theoretical foundations, pathology, planning, and research design. The summary of the research from 2009-2018 has been detailed in Table 1.

Theoretical Foundations

• Conceptualization of ecology

The term "ecology" is derived from the Greek words "Oikos" (home) and "Logos" (study). Therefore, the study of the environmental house includes all the organisms that live in it and all the functional processes that make the house livable. Thus, ecology is the study of "life at home," with emphasis on "the totality or pattern of relations between organisms and their environment," which is a standard dictionary definition of the word (Mish, 2004). Ecology was a practical concern in early human history. In a primitive society, all people needed to know their environment for their survival, that is, to understand the forces of nature and the plants and animals around them. Due to technological achievements,

Table1. Landscape Researchers in the area of ecological urban planning in the world and Iran and their research activities in ecological urbanism. Source: Authors.

Researcher	Research activities in ecological Urbanism	Year of Research
Dabiri & Masnavi (2015)	Landscape-oriented ecological urbanism	2009-2017
Mostafavi (2013) Doherty (2013) Steiner (2011) Alberti (2008) Andermatt Conley (2013) Hodson & Marvin (2013) Konjian Yu(2016)	- Ecological urbanism, contemporarily urbanism - Effect of planning & ecological infrastructure in urban designing - Preserving environment in cities in approach to ecological urbanism	2010 - 2016
Reed (2010)	- Ecological approach related to "Complex adaptive systems" - Change & flexibility of human approaches in face of nature	2010
Hagan (2010)	Creating" artificial ecosystem" cities Assessment of vacant land for construction Environmental metrics & urban design	2013
Bélanger (2016)	- Landscape as infrastructure - Economics is inseparable from ecology	2013
Yousefi Najafabadi (2016)	Inner city nature protection to improve ecological characteristics in cities	2016
Dabiri (2018) Habibi (2010) Ahmadi (2014) Alehashemi (2014) Zare (2018) Sharif Shahidi (2002)	PhD Theses: - From Urban Development to Landscape-oriented Ecological Urbanism - Analysis of Factors Contributing to the Formation of Landscapes - Ensuring Sustainable Environments - Landscape Restoration Methodology - Urban Infrastructure as Landscape Infrastructure - Policies and Governance Impact Maps of Floods on Metropolitan Shiraz - The Theoretical Framework of The Sustainable Landscape Design Process	2011-2018
Bibri. (2020) Colding et al. (2022)	- Eco- urbanism with regard to sustainable environment - Eco-urbanism based on socio-ecological components and - Analyzing resilience and space syntax data reversing the trend of urban ecological illiteracy through affordance designs that connect people with nature and with each other	2020-2022

today it seems that man is less dependent on the natural environment for his daily needs. Many of us forget our constant reliance on nature for air, water, and, indirectly, food, as well as waste absorption, recreation, and a variety of other services. Also, economic systems of any political ideology value man-made things that primarily benefit the individual, but do not place a quantitative, material value on nature's goods and services that benefit us as a society. Until a crisis occurs, humans tend to take natural products and services for granted. We assume that natural resources are unlimited or somehow replaceable by technological innovations, even though we know that the necessities of life, such as oxygen and water, may be renewable but not replaceable (Odum & Barrett, 1971).

• Ecological urbanism

Like all living things, cities need energy, materials, water, and nutrients to address the necessities of life and shelter for their citizens, produce goods and services, grow, and eliminate waste and pollution (Kennedy, Cuddihy & Engel-Yan, 2007). Like the metabolism of a living organism, which is the result of cooperation between the brain, organs, and enzymes, urban metabolism is facilitated by the management policies of the city, its infrastructure, and its citizens. Today, we are witnessing the growth of cities on a large scale, whose expansion is a must to match the influx of population. They need to develop urban services and gray infrastructures, which in turn increase emissions, waste, and wastewater production (Kennedy, Cuddihy & Engel-Yan, 2007; Kötter & Friesecke, 2011). This means that though urban systems depend on ecosystem services, they also threaten similar ecosystems through resource use, land abuse, and pollution production. In fact, the cycle of modern urban metabolism creates environmental changes on a local to global scale and affects land use and earth cover, biodiversity, water systems, biochemical cycles, and climate (Grimm et al., 2008). In recent years, it has become widely recognized that, given the present rate of global urbanization, the only way to improve city living standards is to address the environment and global ecological aspects. The United Nations estimated in 2014 that urbanization will expand from 3. 9 billion to 6. 4 billion by 2050, over most people's lifetimes. In other words, the urban population will increase from 54 to 64% of the total global population (United Nations, 2014). Human activities, in reality, dominate the entire ecology. Urbanization is a significant contributor to this shift. Today, the world needs cities that are designed and developed in line with environmental resources, that take initiatives to revitalize natural resources, offer solutions for economic and social issues as well as environmental issues, and are ecologically responsive to citizens and the environment. Pollution and degradation of environmental quality directly cause degradation in living conditions and quality of life, as well as a reduction in the richness of urban environments. Although natural spaces are artificially created in today's urban planning, they have no ecological role. Preserving the ecological nature of the urban environment means that the city continues to live in solidarity with the environment (Taghvaei, 2016; Yousfi Najafabadi, 2016; Sheybani, 2010; Bahreini, 1998). Richard Furman (2014) in his book, "Urban Ecology", considers ecology a powerful force to save contemporary cities with all their physical and social shortcomings. According to him, the special and effective presence of nature in the city, the analysis and real treatment of human interventions, and attention to the nature of the city in the formation and development of cities will lead to a more promising future for cities, although it will increase their population. Forman's best and most useful urban ecology idea for building and improving urban areas requires investigating the interactions of organisms (microbes, plants, and animals), artificial structures (roads and buildings), and physical environments (soil, water, and air) in which people are densely settled (Haeri & Esmaeeldokht, 2022, 61).

• Ecological nature of urban rivers

Urban natural landscapes are a coherent and integrated network of natural habitats and ecosystems in cities, which are connected by physical, functional, microclimatic, animal, and human flows. Among the natural urban landscape elements, urban rivers have a specific and important place. The reason is that urban rivers and green spaces formed around them are one of the most important factors in shaping the city's morphology and main structure and serve as a factor in urban ecological sustainability (Dinarvandi, Salehi, Yavari & Shakerzadeh, 2013). The green corridors, running water, corridors of good air, and beautiful natural landscapes are important elements connecting the city, nature, and man (Pasban Hazrat, 2012). Urban rivers affect the ecological conditions of cities. Regarding the ecological nature of urban rivers, they are recognized, evaluated, and analyzed in the following three study areas: the process and performance of river watersheds; urban rivers under blue and green infrastructure; and urban rivers under ecological infrastructure.

- The process and performance of watersheds

In natural conditions, rivers involve a range of geomorphological, hydrological, and biological processes. The water flow in the river corridor distributes food and organic materials and provides a habitat for animal and plant species. Rivers and floodplains are affected by hydrological processes are the watershed scale; irregular riverbeds (meanders), runoff storage ponds, and the accumulation of plants significantly reduce the speed of water and consequently floods. Flood ponds, lakes, and wetlands have a slow flow, and by storing water, they reduce a significant amount of flood discharge downstream (Beechie & Roni, 2012) and have an impact on the river's biological structure. Water pools in floodplains provide ideal conditions for

plant growth and the feeding and reproduction of riverine wildlife (especially birds) (Pretty et al., 2003; Stanford, Frissell & Coutant, 2006). It is worth mentioning that the vegetated areas have created roughness and can slow down the flow of water (flood), even if there is a flood beyond capacity. Furthermore, vegetation contributes to the expansion of animal habitat and biological diversity, as well as the establishment and maintenance of biological species communities (Poff et al., 1997; Richter, Mathews, Harrison & Wigington, 2003). The structure of the river corridor and the interactions of the floodplain affect the movement and storage of inorganic sediments and organic materials. Organic matter (aquatic plants, algae, and mosses) is primarily produced in streams and riverside areas (leaf litter, seeds, and terrestrial invertebrates). Smaller particles such as seeds are deposited in narrow waterways or captured by aquatic and coastal plants (Gurnell, Thompson, Goodson & Moggridge, 2008; Richardson, Zhang, 2010; Hoover, Marczak, Richardson & Yonemitsu, 2010). Therefore, biological processes in the river flow affect the structure and functioning of river ecosystems, including habitat selection, feeding, competition, and hunting. Therefore, intact river environments provide a variety of ecosystem services. Unfortunately, in decision-making associated with urban planning and the development of watershed systems, both the maintenance of river ecosystem conditions and ecosystem services have not received much attention and have been ignored (Georgiou & Turner,2012; Gilvear, Spray & Casas-Mulet, 2013). The reason is that this effect is not tangible in the short term. Only in the long term will the loss of ecosystem services and hydrological and biological disturbances cause ecological damage, which is going to take time and exorbitant costs to compensate for.

- Urban rivers of ecological infrastructure

Urbanization and the water cycle of rivers are among the most important morphogenetic factors that describe landscapes. In natural conditions, water effectively and efficiently performs basic environmental functions. In addition, the river is an ecological infrastructure that ensures hydrological, geological, biological, economic, social, and cultural functions (Allan & Castillo, 2007). Rivers, especially in cities where population growth and urban development cause density, less permeability, and increased flood risk (White, 2012), In modern cities, water infrastructure is often designed as a linear system, a collector for the rapid loading of rainwater and waste from urban environments, which leads to severe ecological and biological water poverty (Walsh et al., 2005). Over the past century, almost everywhere, waterways and rivers have been heavily restructured and engineered to maximize space for urban growth. In some cities, they have become a place to collect garbage and urban sewage. Limiting the width of the river to obtain developable land for settlement and transport infrastructure has serious consequences for hydrogeology, the environment, and ecological services. Indeed, until now, the two policies of urban environment preservation and urban development have taken opposing paths (Brown, Keath & Wong, 2009). Looking at the ecological nature of rivers (Table 2) at the macro and micro scales reveals that the ecological services provided by urban rivers serve multiple purposes, and urban ecological development is only possible with the collaboration of experts from different interdisciplinary fields.

- Urban rivers of green and blue infrastructure

The total gray, green, blue, and human infrastructures make a city. The coherent and stable structure of the city is the result of the interaction of these infrastructures. Green and blue infrastructure (GBI) aims at increasing urban resistance and flexibility against climate change and improving the coping and adaptive capacities of natural potentials in cities. GBI uses ecosystem function to provide multiple benefits, enhance the water balance regime, and reduce urban runoff discharge after floods and storms. It can also reduce soil erosion, clean runoff, increase water quality, ensure seasonal water storage, and increase urban groundwater storage (Voskamp & Van de Ven, 2015). Green and water infrastructures can help curb the negative effects of weather-related hazards, including storm surges, heavy rains, and floods. Rivers are among the best water and green infrastructures, especially in urban areas, because they maximize the efficiency of ecological and hydrological connectivity; in fact, river restoration projects reduce ecological and environmental damage and associated social, economic, and environmental impacts. When green and blue infrastructures are proactively planned, developed, and maintained, they can provide a framework for urban development, economic growth, and nature conservation (Tzoulas et al., 2007). In this context, contemporary urban design can reduce the negative effects of human activities on the environment, reduce environmental issues in human health and quality of life, and reduce ecological and environmental imbalances with the help of inner-city rivers.

Conceptual Model of the Theoretical Foundations of Research

In this research, the conceptual model of the theoretical foundations, based on the literature review and conclusions made, can be seen in Fig. 1; Based on this, the ecological nature of urban rivers in the framework of ecological urbanism is extracted by examining the ecological infrastructure, the process and performance of watershed, water and green infrastructure of rivers in the city, and achieve the strategy of river restoration. Then it formulates effective components and ecological strategies.

Table 2. Dimensions of ecological nature of urban rivers on planning macro & micro scale. Source: Authors.

Dimension of ecological nature of urban rivers	Ecological nature Macro scale	Ecological nature Micro-scale
The process and performance of watersheds and the health of inner-city rivers (Effective in the structure and function of the ecosystem)	River health Preserving hydrology of the river Guaranteeing functions: hydrological, geological, biological, economic, social, cultural	Water conservation (basic hydrological function) Maintaining proper water quality Protection of natural water & soil resources Creation & protection of biological elements Natural ecosystem services Flood mitigation & reduction of natural hazards Water transport (flooded rivers)
	Controlling the intensity of river flow Controlling floods	Reducing the intensity of flood flow (creating storage ponds) Sediment controls (storage of organic & inorganic sediments) Preventing chemical interactions Runoff control Redistribution of underground water The formation of the natural water cycle
Ecological infrastructure (Effective in ecological urbanism)	Biodiversity	Increasing animal habitats & vegetation in the riparian zone Support & maintenance of species communities
	Biological process in water flows	Selection of animal habitats, feeding competition &hunting of animal species
	Ecosystem services	Formation of ecosystem services such as pollination, nutrient cycling, natural water purification
Green & blue infrastructure	Resilience against climate changes and environmental hazards Improving natural adaptive capacities in the city	Reduction of urban runoff resulting from floods Purification of runoff Increasing the water balance regime Reducing the soil erosion on the bank river Increasing underground water storage Increasing the quality of underground water
	Improving and adjusting urban environmental conditions	Increasing green urban spaces
	Increasing the efficiency of ecological & hydrological connection of urban rivers	Reducing ecological & environmental damages Reducing economical & social damages

Research Findings

The development of cities adjacent to rivers causes damage to the ecological nature of urban rivers, which is affected by human interventions, urban development, and constructions adjacent to the riparian zone, which is analyzed in two parts: A: urban runoff in the riparian zone; B: human impact on river structure.

• Ecological damages on urban rivers

- Ecological injuries on urban rivers

The development of cities adjacent to rivers causes damage to the ecological nature of urban rivers, which is affected by human interventions, urban development and constructions adjacent to the river boundary, which is analyzed in two parts: A: Urban runoff in the riparian zone and B: Changes in the structure of rivers caused by human activities.

A: Urban runoff in the riparian zone: Pollution in urban areas has a great impact on water quality. The effects of rainfall on vegetation and hard-built surfaces are very different. Floodwater management is one of the most important issues that should be considered in urban areas. The maximum amount of rainfall absorption occurs on plants, where it is absorbed in the soil and eventually joins the underground water network or is transferred to the atmosphere. Water is not absorbed by hard surfaces such as asphalt and concrete and enters rivers as runoff through drainage systems (Dunnett & Kingsbury, 2008). According to the research of the United States Environmental Protection Agency (EPA), this runoff is contaminated with industrial sewage, cars, and residential and commercial sewage, which, in the case of the absorption of polluted flood runoff from the surface of urban roads, contaminates the water tables below. The land affects the quality of urban water. Because urban populations often use concentrated water sources, this pollution causes environmental and public health risks, such as reduced drinking water quality. Growing urbanization has also been shown to have significant impacts on natural organisms (Grimm et al., 2008). In many cases, fragmentation and pollution cause discontinuity in ecosystems and result in biodiversity loss. The greater the amount of land covered with impermeable materials (such as concrete, cement,

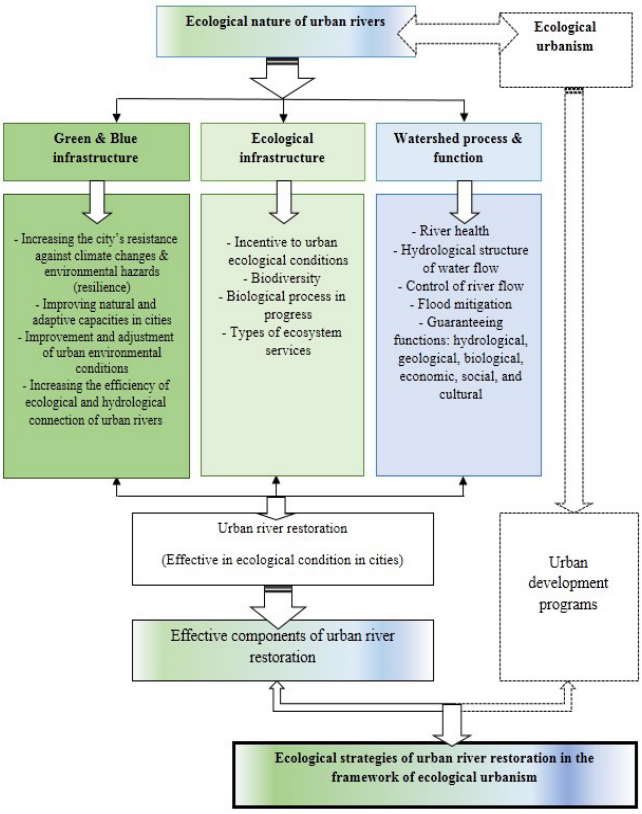

Fig. 1. A conceptual model of the theoretical foundations of the research. Source: Authors.

and asphalt), the less water will be absorbed by the ground, the possibility of evaporation of surface water will decrease, and the amount of runoff will increase. One of the basic functions of a healthy hydrological system is to conserve water, allowing for the regulation of runoff and the redistribution of groundwater. The natural water cycle, including the infiltration of rainwater into the ground, is gradually filtered into rivers and underground water because land covered with vegetation has a normal sponge effect and absorbs water, which reduces the volume of water and slows its movement. Meanwhile, impervious urban surfaces often act like "umbrellas" and increase storm runoff. Since water tends to flow faster, the reduction of permeability caused by the artificial structure of urban rivers causes an increase in the amount of surface runoff, hydrogeological instability, and flooding (Shuster, Bonta, Thurston, Warnemuende & Smith, 2005).

B: Changes in the structure of rivers caused by human activities: Changes by human activities can influence the flow of water, and the shape of the river (for flood control management), resulting in a rise in water resources, supplying hydroelectric energy, providing agricultural needs, industrial needs, and navigation. In addition, river systems have changed drastically due to urban growth. The rivers are constantly under the pressure of urban pollution due to extensive and high exploitation. Rivers are often used as waste channels (for sewage waste and the disposal of toxic chemicals) and cause the spread of pollution. Numerous dredgings, high fishing (rivers full of water), removal of coastal vegetation and water vegetation, changes in the water flow regime, and the introduction of alien (non-native) plant species have reduced the natural complexity of river landscapes and caused the loss of their ecological functions (Ward & Stanford, 1995; Ward, 1998). The integrity of the river ecosystem has been disrupted due to human activities, and its compatibility with the main function of the ecosystem has been lost, affecting the hydrology, quality, and structure of water flows. Primary ecosystem processes are negatively affected by these processes, and as a result, degraded rivers provide fewer ecosystem services (Gilvear, Spray & Casas-Mulet, 2013). Table 3 shows how the ecological damages caused by human activities in urban development have affected urban rivers on a large and small scale.

- Restoration of urban rivers

This study first attempts to examine the restoration of urban rivers, which are one of the most valuable natural urban landscapes in terms of concepts, principles of the restoration of natural organisms, components of ecological restoration of urban rivers, and process-based restoration. Then, it explains the restoration strategies of urban rivers in detail. The concept of restoration: changes in landscapes over time are caused by human intervention or natural disturbances. Such changes have caused disturbances in the structure and processes of the landscapes. This disorder occurs both in

Table 3. Ecological damages of cities on rivers on macro and micro scales. Source: Authors.

Research	Ecological Damages Macro-scale	Ecological Damages Micro- scale
Urban runoff management in rivers	Formation of urban runoff affected by gray infrastructure (asphalt roads, cement sidewalks, concrete surfaces, etc.)	- Wasting rainwater and not using it to irrigate vegetation in urban public places - Lack of formation of underground drinking water sources
	Transferring urban runoff to the rivers through the drainage	- Changing the natural hydrological structure of rivers - Increased flow &flooding in some areas
	Combining urban runoff with sources of pollution (Industrial sewage, mobile sources (cars), residential and commercial sewage, etc.)	- Reducing the quality of urban drinking water sources - Creating environmental & public health risks - Disturbance in the continuity of the river ecosystem - Reducing biodiversity in the river ecosystem
	Removing pollution from urban runoff to clean water sources	
Changes in urban rivers caused by human activities	Development of the city and changes in the natural morphology of the river (reduction in the width of rivers due to the development of settlement land and the construction of urban transport infrastructure)	- Separation of river sections - Reducing the natural complexity of river banks & landscape - Converting river into the municipal sewage - Converting the river into a quick rain-loading channel
	- Interfering with the integrity of the river ecosystem - Change in rive water flow (flood control & river canalization)	Changing water quality: increase in turbidity and suspended solids/increase in nutrients (nitrogen, phosphorus) / change in water pH
		Changing the water flow regime: increasing the flow intensity/ increasing the maximum flow speed/decreasing the minimum flow speed
		Reducing the stability of the basins due to erosion & sediment
		Changing food-energy resources: changing the type, quantity, and size of organic matter particles / reducing coarse suspended organic matter / increasing the production of algae and organic dust
		Creating different biological interactions: changing the structure of animal and plant habitats/increasing the percentage of non-native and invasive species/homogeneity of the habitat and decreasing the diversity of species

the vegetation and animal communities and in the cultural perception of the surrounding environment and human activities. Therefore, the destruction and degradation of natural ecosystems are known as the most important issue today. Therefore, in urban planning and urban design, and environmental landscape design in cities, among those issues that have been frequently discussed, we can refer to the attitude of rehabilitating the natural landscape, which protects what remains and restores that part of nature that has been structurally disturbed (Pouryousefzadeh, Bemanian & Ansari,2012). The most important concern in restoring natural ecosystems is protecting the continuity of plant and animal species and their communities, societies, and processes. All approaches focus on the continuity of forms and processes in natural ecosystems (Farina, 2006). Restoration includes regenerating ecosystems, controlling weather pollution, preventing acid rain, and protecting habitats. One of the main opportunities and facilities for rehabilitating natural organisms is creating new relationships between people and natural ecosystems. This restoration can or should be done everywhere and applied to any ecosystem with a damaged natural substrate. It is suitable for the creation of secondary ecosystems similar to the destroyed natural ecosystems so that the natural quality of the substrate can be expanded, which limits human activities and interferences in nature (Ahmadi, Bemanian & Ansari, 2018).

- Components of ecological restoration of urban rivers

The revitalization of the river in fully urbanized areas can help change people's perceptions of green space and its public resources, but often has little effect on natural processes and habitats. Both growth of urbanization and climate changes threaten the water ecosystems of cities. This will lead to the continuous loss of plant and animal habitats. Therefore, in this context, it is necessary to protect the habitats with the desired quality, which are prioritized for restoration. Researchers such as Philip J. Bone et al. (Boon, Morgan & Palmer, 1992), Pedroli, De Blust, Van Looy and van Rooij (2002), and Beechie and Roni (2012) state five strategies for facing the challenge of "river protection" regarding the

health status of the river: protection before development, limiting development, reducing negative effects, restoration, and release. With a comparative-inferential analysis, we understand that urban rivers have been affected by human interventions due to urban development. Urban development has taken the rivers out of their completely natural status and changed their natural flora and fauna ecosystems. This means that there are no suitable conditions for "pre-development protection" and "development limitation."

On the other hand, urban rivers are part of the nature of the city, and "releasing" those means destroying a part of the urban environment. Therefore, "reduction" of negative effects and "restoration" are correct strategies that can be effective in facing the ecological nature of the river in the urban environment. Since restoration is impossible without reducing negative effects, the strategy of "reducing negative effects" is part of the "restoration" strategy. As a result, when it comes to ecological approaches, the focus should be on the "restoration" of urban rivers. River restoration aims to improve the natural function of the river and its landscape as a diverse network of habitats, including the function of the river's corridor for the watershed, and to increase rivers' resilience to environmental hazards.

River restoration has been a key strategy to improve environmental quality and biodiversity in recent decades. With increasing emphasis on the value of river performance and the ecosystem services provided by waterways, interest in river restoration has increased significantly (Lemons & Victor, 2008). The term "river restoration" refers to the rehabilitation and renewal of biological species, the strengthening, and development of habitats, improving the condition of the river ecosystem, strategies, bed revitalization strategies, and revitalization and flood mitigation (Fig. 2) (Beechie & Roni, 2012). In the studies, Masnavi et al. (Masnavi, Tasa, Ghobadi, Farzad Behtash & Negin Taji, 2016) found that the restoration of urban rivers is affected by four main factors: environmental factors, urban space, cultural-social factors, and political-economic factors. The factors were shown to contribute to the restoration of the river, which is important to urban sustainability. Environmental factors include hydrology, vegetation, and micro-climate indicators, and urban space factors include urban infrastructure, accessibility, and the urban environment. Mental image and public perception are effective in the field of socio-cultural factors, and political-economic factors depend on economic and financial resources and their distribution. Finally, the set of these factors forms the diversity of biological species, the formation of ecosystem services, the connection of green ecological paths, and the formation of public institutions for support and cooperation (ibid.).

- Process-based river restoration

In recent years, the concept of process-based river restoration has been frequently raised. This integrated ecological-social approach is matched with comprehensive techniques to address the major causes of ecosystem degradation and create a new balance between socioeconomic needs and sustainable watershed management (Brierley & Fryirs, 2004; Kondolf et al, 2006; Bennett, Peterson & Gordon, 2009) In addition, it focuses on preventing human interference in natural processes, increasing the resilience of river ecosystems in the face of future disturbances. Process-based

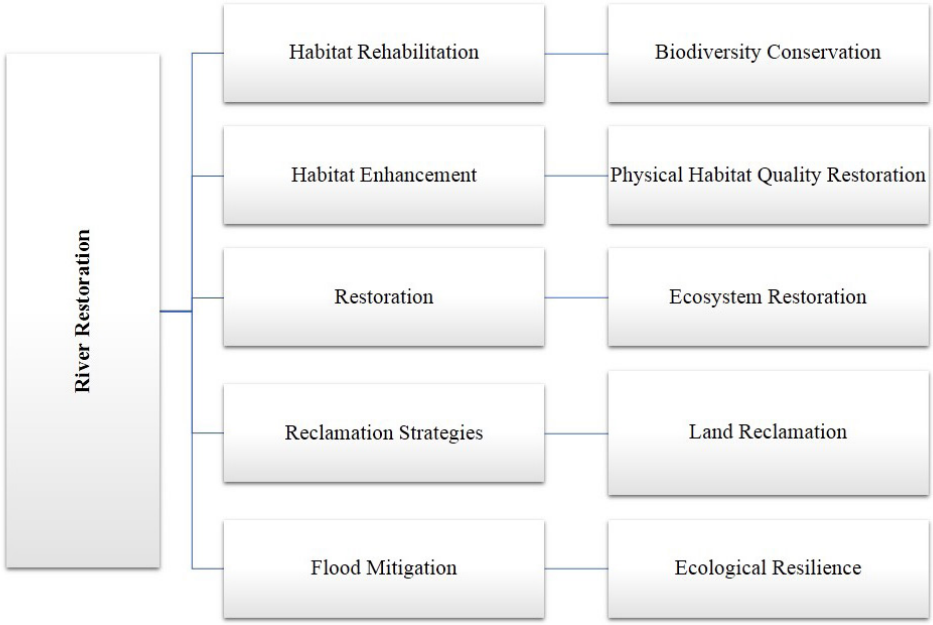

Fig. 2. Components of urban river restoration. Source: 2012. Source: Authors Adopted from Beechie & Roni, 2012.

improvement ensures that programs and actions support the restoration of the coherent structure of the river ecosystem without the need for continuous human intervention. The goal of "process-based remediation" is to "redetermine the rates and magnitudes of the primary physical, chemical, and biological processes that create and maintain the river and floodplain ecosystems themselves" (Sear, 1994; Beechie et al., 2010). The recognition of this process is based on the analysis of various causes, which, in addition to ecological issues, are raised under the influence of social and economic factors at the local, regional, and national levels to maximize the benefits in the short term, midterm, and long term as measured in urban planning (Beechie & Roni, 2012; Gilvear, Spray & Casas-Mulet, 2013; Sabbion, 2017) The purpose of this assessment is to examine urban developments within the framework of ecological urbanism. This would aid in the planning of actions required for the restoration of rivers as urban environments while maintaining ecological identity over time.

- Strategies for ecological restoration of urban rivers

In many cities, there are urban rivers whose ecological nature has been neglected. Sometimes, in some cities, they have been canalized, and the riparian zones have gone out of their natural state. In some other urban areas, often to create space for urban settlements, small rivers have been piped and buried under roads and passages. Due to these conditions, the necessity of restoring the rivers and redesigning their areas has been highlighted to preserve the ecological nature of the rivers. For this purpose, the following strategies are developed to improve the conditions of urban rivers:

A: Reconstruction of the geomorphology of urban rivers: In developed watersheds, the covering of impermeable materials (cement, concrete, asphalt, etc.) destroys natural habitats. In this way, the restoration measures are mainly focused on the re-naturalization of the river area by protecting the natural area of the river, restoring the shape of the land in the damaged areas, removing concrete and inflexible structures, designing natural areas and twists, and planting and cultivating trees and bushes within channels. Engineering techniques appropriate to the conditions of the plant and animal habitats reduce the erosion of river areas and improve the coastal habitats within the river boundaries (Sabbion,2017; Masnavi et al., 2016). Re-establishing the geomorphology of the river and creating a dynamic balance based on the environment is one of the main goals of restoration (Riley & Leopold, 1998).

B: Protecting the health of the river: the effectiveness of the structures appropriate to the morphology of the river to protect the river area and prevent the movement of the channel may create a disturbance in the processes of the watershed and affect factors such as the connection and cohesion of the river, sediments, and hydrology. Therefore, sustainable watershed management is necessary. The conventional restoration strategies include reducing or recovering sediment supply, reducing or recovering runoff, and improving hydrology, especially in sediment settlement areas. These are possible with the following solutions: natural drainage of systems, resurfacing of surfaces, stabilization of river areas, addition or removal of top-open culverts, the addition of surface water drainage pipes at road intersections, and reconstruction of roads with permeable materials (for runoff) (Bagley, 1998; Novotny, Ahern & Brown, 2010). Improving the flow of urban rivers provides an opportunity to quantify and integrate physical, chemical, and biological processes to restore damaged ecosystems.

C: Connection of green patches to create an ecological network and prevent their fragmentation: sometimes there are patches of vegetation in the area adjacent to the river, which should be expanded with local plant species and connected to other patches to create a green buffer and form a coherent ecological network. In addition, it protects the river's privacy and prevents excessive urban development (Masnavi et al., 2016). Green patches are part of the river ecosystem and affect the ecological function of the river and the provision of ecosystem services.

D: Reduction of human interventions in natural processes: interventions in urban areas that are dense and accommodate residents require planning and implementation of measures on the connection of the river. Human interventions (urban development) usually harm the connectivity of watersheds while reducing the capacity of physical, chemical, biological, and ecological processes (Paul & Meyer, 2001). In many cities, there are programs to restore water bodies that are activated in the short term (in particular, to build urban infrastructure and maintain river flow characteristics) (Nilsson et al., 2003; Walsh et al., 2005; Brooks, Palmer, Cardinale, Swan & Ribblett , 2003). If these types of measures continue and the privacy of the watersheds is protected from human interference, the hydrological characteristics of the river will be preserved, and as a result, its ecological nature will also be preserved. For this purpose, the presence of citizens in the river should be limited, and cultural measures should be taken to protect the natural environment of urban rivers.

E: Flood control: To control the flood, urban construction related to rivers should be limited so that the river bed maintains its natural shape and, as a result, does not turn into channels with impermeable and water-resistant materials such as concrete surfaces (Masnavi et al., 2016). Impermeable materials have little roughness and increase the flow intensity. If calm ponds are created in the river bed, it will reduce the flow, increase the absorption of water in the underground layers, and reduce the intensity of floods. Also, increasing the layers of vegetation on the river bank reduces the speed of the flow.

F: Preventing polluted sewage and runoff of the city into

the river: the development of urban spaces and the creation of urban sewage infrastructures cause pollution of water resources and soil in the river. In addition, due to economic problems and cultural ignorance about the environment, in many urban areas, sewage and runoff of urban roads and some gray sewages are directed towards urban rivers, and this has ultimately caused environmental pollution, the destruction of the ecological network, and the loss of some plant and animal species. Establishing a suitable drainage system for sewage near the river and treating urban runoff before entering the riparian zones will significantly reduce pollution. Therefore, expanding the structure of urban development with rivers requires the development of ecological strategies and planning to preserve both the ecological nature of the river and to carry out urban development under urban ecological conditions. In Figure 3, the strategies of "process-based restoration of urban rivers" can be seen in macro and micro planning scales according to ecological goals.

Discussion

Urban rivers have an ecological nature that can be considered as urban ecological infrastructure. Rivers are a living and dynamic ecosystem of plant and animal species that form the "river ecosystem" in the vicinity of the blue and green corridors of the river. As a natural phenomenon, the river ecosystem is affected by the flexible and changeable structure of nature and changes, completes, and improves during successive times; therefore, the restoration of damaged urban rivers is "based on the process." Over time, the process of evolution and restoration takes place. This means that in the short term, a definite result cannot be obtained, and complete restoration is not possible. One of the goals of ecological urban development is to rehabilitate

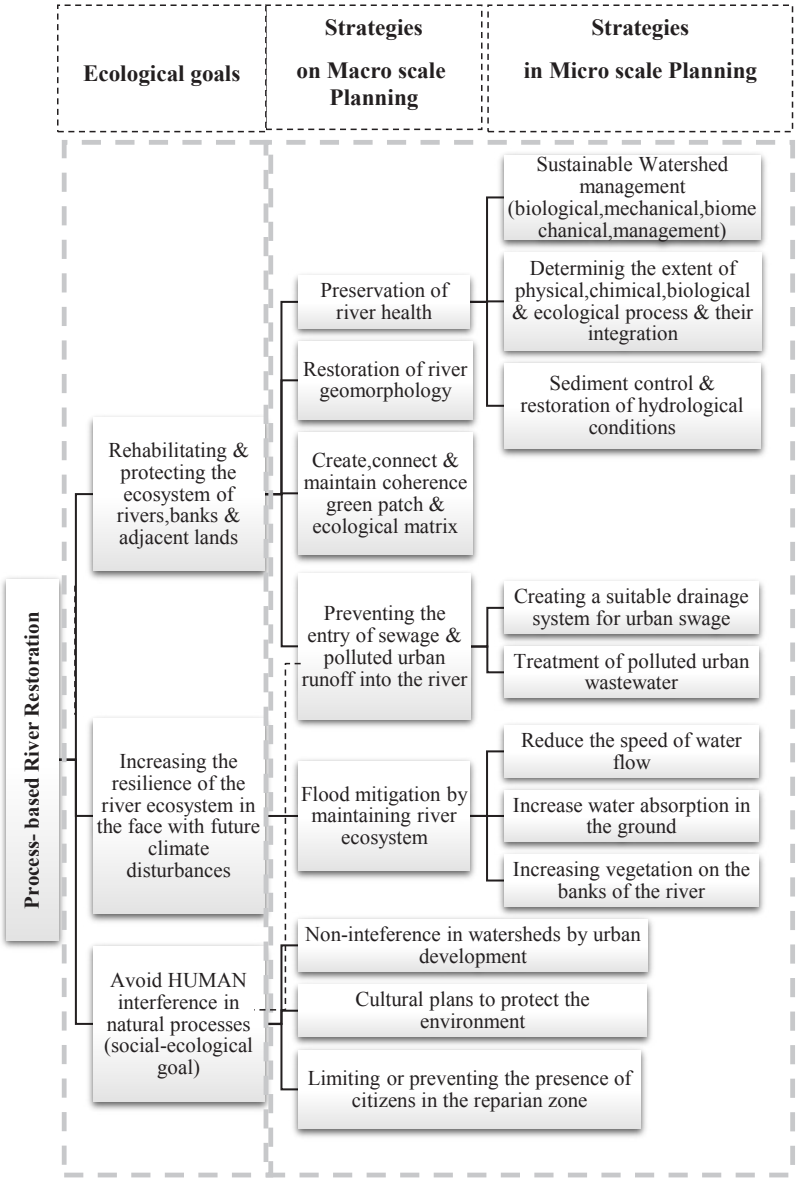

Fig. 3. Goals and Strategies for Process-Based River Restoration planning on Macro & Micro scale. Source: Authors.

and protect the ecosystem of urban rivers and their banks and adjacent lands in the city, which is possible with the following strategies in urban planning on a large and small scale:

A: First of all, the causes of ecosystem destruction should be identified. Then, with sustainable watershed management, determination of physical, chemical, biological, and ecological processes and their integration, control of sediments, and restoration of hydrological conditions, water quality will be improved and the health of the river will be restored. To protect water quality, it is necessary to prevent the entry of polluted runoff from roads, urban and industrial sewage, etc. In this case, the urban waste system must be designed and built with proper management so that it is both responsive to the urban infrastructure and free from environmental pollution. Urban runoff water should be treated as gray wastewater and reused if its quality is improved.

B: If it is possible to make changes in the urban texture, the geomorphological structure of the river should be modified, but as long as it has the potential to change (in the scattered urban texture adjacent to the river or the lands around the cities on the river bank), the natural form of the river will be protected. Related areas should be improved so that the river flows in its natural form (meander). In this case, the hydrological structure of the river will also be restored, and the speed of the flood flow will decrease in case of a crisis. In this case, the banks of the river will be returned to it, and within the boundaries of this water infrastructure, green infrastructure, and vegetation will also have the possibility to grow and multiply. In this way, it will be possible to create connection and coherence in the green corridors. Subsequently, the species of birds and animals (limited to urban life) also increase, and the biological ecological network is also restored.

D: Another ecological goal is to increase the flexibility of the ecosystem of urban rivers in the face of climatic disturbances and environmental hazards. Due to climate changes in consecutive years and weather changes in many seasons, there is a possibility of floods. Therefore, due to the proximity to the urban texture and the occurrence of possible risks, flood control is one of the requirements of urban management, which should be included in urban planning. Different strategies such as creating and maintaining the natural morphology of the river, creating and spreading vegetation in the riparian zone (green corridor), the presence of natural textures of materials in the river bed, and not using impermeable materials in the bed and body can reduce the speed of water flow. They also increase the amount of water absorption in the land (covering permeable materials), which reduces the volume of runoff and the possibility of flooding. These are purely ecological measures that must be accompanied by security and social measures for citizens in the river's watershed to prevent accidents.

E: Urban rivers are affected by the presence of human communities due to their presence in urban contexts; therefore, in addition to ecological goals, social goals are also involved. The presence of citizens within the boundaries of urban rivers is inevitable and occurs as a result of human interventions and disturbances in the natural processes of the ecosystem. Preventing the interference of human activities in the river ecosystem is one of the socio-ecological goals that can be achieved by planning and formulating improvement measures in accordance with urban development, creating restrictions on the presence of citizens in the river, and changing people's attitudes in the field of protecting the natural river bed and habitats. Dependency and culture-building can be controlled in the face of nature. To reduce human interference in the long term and continue to restore the ecosystem.

Conclusion

Urban rivers are among the living and natural urban organisms that have an ecological nature. The rivers have been damaged and changed due to urban development on the banks of the river and the development of gray infrastructure. The river ecosystem has been disrupted and has lost its nature. Certainly, the ecological restoration of the ecosystem of inner urban rivers is a strategy aligned with the framework of ecological urbanism and its goals. Given the river's natural state, as well as climate change and environmental hazards, the best method for restoring the river's ecological nature is "process-based restoration," which, if included in urban development plans with ecological goals, will result in cities being developed within the framework of ecological urbanism. Therefore, it is necessary to develop strategies to improve the ecosystem of rivers, protect their banks and adjacent lands, increase the resilience of urban rivers and cities against environmental hazards, and prevent human interventions. These strategies are effective in urban planning on multiple time scales (short-term, long-term) and lead to the restoration of the ecosystem of urban rivers and the restoration of the ecological nature of the river and the city. If we review the goals and functions of restoring urban rivers, they can be divided into three general categories: hydrology, ecology, and morphology. Such strategies should find a special place in urban development planning. They need to be developed in accordance with urban planning. In this way, they can be sustainably implemented. Since the restoration of urban rivers is "process-based," it is necessary to monitor and evaluate its implementation and post-implementation (Fig. 4). Since all urban development programs are aimed at providing services to citizens and the creation of urban infrastructure is also done for this

purpose, limiting or prohibiting the presence of citizens in the river area is not justified in urban planning. This is in conflict with maintaining the ecological structure of the river (and even all urban environments). Therefore, the presence of citizens or the creation of restrictions on the use of the river is placed in the scope of aesthetics and urban landscape (which is not within the scope of this research). Therefore, developing strategies for the ecological restoration of urban rivers in the framework of ecological urbanism requires four stages: project identification, project formulation, implementation of strategies based on goals, and monitoring and evaluation of the project. It is worth mentioning that in every climate and territory, rivers have a unique nature that affects the strategies of "river ecosystem restoration." Therefore, such strategies need to be in accordance with urban planning to be sustainably implemented.

"Wrong urban development" has resulted in the restoration of urban river ecosystems. Due to the necessity of "protecting the ecological nature of urban rivers," it is logical to take environmental measures before destroying the ecological structure of rivers and answer these questions: How to plan the development of future cities (from the beginning) according to the ecological nature of natural organisms within the city (especially rivers) What

Implementation and Planning stages with the aim of Sustainable Urban Development

Ecological components of River Restoration	Project Identification	Project Formulation (Based on goals & strategies)	Project Implementation (Based on techniques &laws)	Project Monitoring & Evaluation
Hydrology	• River health status (water quality & watershed performance) • Hydrological structure of water flow (flow regime) • Water use • Water flow control (water storage potential)	• Integrated management of the river basin • Sediment control (storage of organic & inorganic sediments) • Preventing the transfer of polluted urban runoff • Water filtration (natural drainage, vegetation corridor, treatment station, etc.) • Continuity of hydrological conditions of the ecosystem	• Implementation based on regional & national policies • Create smart goals against results • Interdisciplinary collaboration • Determining evaluable criteria & goals for river restoration • Selection of appropriate techniques with implementation facilities • Determining the amount of risk & uncertainty • Prioritizing restoration actions • Short- & long-term plan • Flexibility in project implementation • Financial planning • Time planning	• Continuous monitoring of the hydrological quality of the river (sampling & testing) • Supervision of natural & artificial drains, treatment stations, etc.
Biodiversity	• Ecosystem health • Ecosystem services • Knowledge of biological diversity • Investigation of biological process in the river • Flood mitigation (resilience)	• Biological river ecosystem restoration • Continuity of biological conditions of the ecosystem • Flood mitigation with biological goals • Protection & management of biological species • Use of indigenous plant species (resistant in the environment & climate of the periods of drought) • Resilience in face with climate change & environmental hazards		• Evaluation of ecological effects on environment • Monitoring ecological processes after implementation • Monitoring the protection & management of biological species
Morphology	• Identify the unique characteristics of the river • Examining morphological changes • Indicators of physical modification & geological changes • Restriction on the use of adjacent lands by law	• Creation of the natural meander form of river • Urban development control in river bank • River matrix ecological restoration (integrated connection of both sides of ecological patches with the river corridor)		• Monitoring the river channel after flood • Reconstruction after environmental hazards • Monitoring & restoration according to the feedback of natural & manual changes

Fig. 4. Developing ecological restoration strategies for urban rivers with the aim of sustainable urban development in the framework of ecological urbanism. Source: Authors.

strategies, in the formation of future cities, will prevent the disruption of urban river ecosystems? How will the gray infrastructures of the future cities be designed, built, and expanded without interference or with minimal damage to the natural ecosystems of the rivers? "Urban development".

Declaration of no Conflict of Interest

The authors hereby declare that there has been no conflict of interest in conducting this research.

Endnote

*This article has been taken from Sanaz Haeri's Ph.D. thesis entitled "Deriving influential factors in the Urban River Restoration through an Ecological Landscape Approach: The Case of Khosk River, Shiraz, Iran," and presents part of the findings of the research. This study was conducted under the supervision of Mohammad Reza Masnavi at Tehran University, Kish International Campus in 2022.

1. Lewis Mumford (October 19, 1895 – January 26, 1990) was a 20th-century thinker and city planner from the United States of America, whose fame is mostly due to his humanistic and philanthropic views. He is a historian of human civilization, an expert on the machine age, an expert on metropolitan cities, and the author of essential theories in urban geography. He is a disciple and follower of Patrick Geddes, and like Geddes, he considers the city a critical place for our time.

2. Urban infrastructures are systems that serve a city or country. Urban infrastructure means roads, bridges, urban sewage networks, etc., which are available to the public although they may be expanded and managed under the cover of the public or private sector (Piryonesi, 2019). The infrastructure of a city is divided into four general categories (Young, Symons & Jones, 2015): 'Gray Infrastructure' includes buildings, urban streets, suburban roads, and facilities. urban or green infrastructure involves urban environments such as forests in or in the suburbs, parks, trees, green walls, green roofs, and agricultural land in or in the suburbs. 'Water Infrastructure' comprises rivers, lakes, waterways, and infrastructure of water-sensitive cities. The last category is 'Human Infrastructure' which consists of social networks, cultural structures, and economic structures.

3. According to recent studies, approximately 80% of the world's population is currently facing severe threats to water security and the destruction of river habitats (Vörösmarty et al., 2010). The World Water Council estimates that more than half of the world's rivers are polluted or at risk of drying up. Only less than 20% of the fresh water in the world is intact and untouched. The loss of natural habitats is one of the first consequences of the destruction of aquatic ecosystems. (Beechie & Roni, 2012).

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