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Original Research Article

Resilience Planning and Design of Urban Rivers in the Face of Flood Disturbances

(A Case Study: The Resilience Planning of the River Darakeh)

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Abstract | In recent decades, resilience planning has been received significant attention by experts from most of the fields, especially landscape architects, in the face of flood and drought disturbances. The River Darakeh, as one of the urban rivers located in Tehran, is highly vulnerable to flood disturbance and its consequences despite the construction of flood-control infrastructures—channels and terraces on the riverbeds. This issue reveals the insufficiency of such plans in controlling the flood. Thus, it is necessary to plan and design the River Darakeh in order to reduce the risk of floods and increase the sustainability of the river. In this regard, this study seeks to fine an alternative approach instead of channels against the environmental problems and consequences of the floods of the River Darakeh. Therefore, this paper endeavors to find answers of the questions: is the new approach to resilience a viable alternative to one-dimensional and engineering approaches to the management of rivers? In order word, how can this approach transform the turbulent environment of the River Darakeh into a sustainable and environmentally and flood-friendly environment? Accordingly, this study employs the descriptive-analytical approach as well as a brief review of the related literature in order to gather various resilience indices. Then, design strategies based on the definitions of indices are extracted, and design solutions for the River Darakeh, as a case study, are presented in the face of flood disturbances. This study relies upon seven indices of resilience thinking—namely, redundancy, diversity, strength, connection, learning, self-organization, and variability—to present several strategies; including environmental and spatial diversity, high-level knowledge, the capacities and skills of indigenous people, the application of past generation's experiences regarding past floods, strength of natural and human-made components, strength of the spatial relations and coherence of design components, and self-organization of social and ecological resources; for designing the River Darakeh to withstand against flood turbulences. This design and planning initiative includes different social and environmental dimensions which can be considered as alternative solutions for the flood control channels and the terracing on the riverbeds. The finding of this paper can be applied as a pattern for chaotic urban rivers in Iran and throughout the world in similar circumstances.

Keywords | *The River Darakeh, Resilience, Resilience indices, Flood, Landscape architecture.*

Introduction| In the recent decade, landscape architecture has faced many challenges due to climatic changes and the government's one-dimensional interventions. These

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challenges can be discussed in different dimensions including ecological, social, economic, landscape, etc. and have been the outcome of either social interventions or environmental dysfunctions which are considered as a great threat for landscape or urban infrastructures (Bahrami, Alehashemi & Motedayen, 2019). Meanwhile, various approaches including resilience and sustainability have been proposed to overcome such challenges. Resilience, as a new concept, defines a new conception of human's relationship with his surrounding, such that this concept has gained significance for the reduction of environmental disturbances in landscape and urban spaces. In other words, the objectives of resilience thinking can be summarized in the reproduction and recovery of disturbance-laden environments for re-organization in the face of severe disturbances (Gharai, Masnavi & Hajibandeh, 2018). It's noteworthy that disturbance-laden environments are the ones with unpredictable and accidental irregularities within dynamic phenomena (Stacey, 2008) which requires short-term and flexible decisions for confronting the disturbances (Hemmati, 2015). Thus, this approach has been recently embraced by urban designers and civil engineers in the recovery ad use of disturbance-laden rivers suffering from environmental problems including floods and drought (Bahrami & Hemmati, 2020; Bahrami et al., 2019).

Urban rivers, especially urban rivers located inside Tehran are faced with several disturbances and problems. In the past, these rivers have been mainly used as natural spaces and air corridors for the establishment of service and recreational activities. Nowadays, these natural spaces have turned into channels for control and absorption of floodwater instead of being used as a space for feeling nature more closely, looking at nature, and as recreational spaces. Thus, these natural spaces have gradually lost their natural significance (Sabokro, 2019). This transformation has been such that these rivers have lost their significance in Tehran city's urban equations and citizens" life quality has been consequently decreased as a result (Karimi Moshaver, 2013). Such changes in land use and transformation of natural river paths to concrete paths for flood control as well as mismatch to the river area, poor vegetation, high precipitation, the existence of steep slopes and shallow lands with a high propensity for flood absorption and other kinds of consequences intensifying the environmental threats, have incurred more damages on the rivers. These damages are such that any probability of flood occurrence with a long recurrence interval, may destroy their environmental, social, and economic infrastructures. Thus, it can be argued that structures such as coastal walls, dams, and channels built for ensuring security against floods, have worsened rivers' conditions in the face of floods due to manipulations in the river's natural structure (Bell, 2012). As a confirmation for the previous proposition, one can refer to civil rivers' flood such as the Mississippi in 1993; Red river in 1997 (ibid.), the river Darakeh in Iran in 1987 (Borna News Agency, 2020), Taipei in Taiwan in 2001, Dresden in Germany in 2002, New Orleans in the USA in 2005, Guangdong in China in 2007, Brisbane in Australia and Bangkok in Thailand in 2011 (Liao, 2012) and the river Kan in Iran throughout consecutive years, e.g. in 2016 (Bahrami et al., 2019).

The river Darakeh is one of the urban rivers located in Tehran. To minimize the threats of floods, urban managers have attempted engineering and one-dimensional actions including the construction of channels and modifications of its bed. However, despite the channel constructions and terraces constructed on the river's bed, this river still suffers from flood's disturbance, such that flood threatens its social and natural bed every year. Also, the extended shape of the river Darakeh, destruction of vegetation, development, and extension of the civil area, and a set of environmental factors have decreased penetrability and increased runoff in the southern part of his basin. Consequently, the height of the runoffs and water flow rate has increased in this river. This increase within the river Darakeh increased the risk of urban floods (Ghanavati, Saffari, Karam, Najafi & Jahandar, 2017). Accordingly, the chairman of the Flood Control Center has mentioned Darakeh drainage basin as one of the prioritized vulnerable rivers in the face of floods (Borna News Agency, 2020). Therefore, this study seeks to answer the following questions:

1. Is the resilience approach acceptable as a modern and innovative approach to be substituted for a one-dimensional and engineering approached for river management?
2. How do the modern resilience approach and its indices turn the disturbance-laden environment of the river Darakeh into a sustainable and environmental-friendly space?

Study hypothesis

This study attempts to extract resilience strategies and approaches during flood for disturbance-laden and dynamic environments by relying on resilience thinking and its indices. In fact, the authors of this study believe that these strategies and approaches that embody all river's dimensions including environmental, social, and ecological dimensions are considered as a good substitute for concrete channels designed for flood control. Moreover, this study attempts to study the impact of the resilience approach in the organization of River Darakeh as a case study in the face of flood disturbances, the results of which will be resilience social and environmental strategies to reduce flood consequences.

Research method

A descriptive-analytical approach has been taken in this study to achieve the study goals and responding to research questions. At first, the resilience indices collected and described by a detailed review of theoretical literature. Then, the design strategies extracted and extended through

analytical approaches based on the definitions proposed from these indices. Finally, using these strategies and indices, different strategies proposed for planning River Darakeh as a case study of a basin entailing dangers of destructive floods.
The data for this study were collected through library resources and field studies. At first, data regarding resilience thinking and its components were gathered from books, journals, and papers taken from credible scientific databases, specifically Scopus, Science Direct, and Web of Science. To collect the data and conduct a review of the related literature, the theoretical literature on "resilience indices" was searched through the use of keywords including "resilience", "resilience indices" and "resilience characteristics" from 1973-2020 in the form of 15 books, 42 papers, and four reports. Due to the perceived overlap and comprehensiveness of theoretical literature, 13 books, 29 papers, and three reports were used. Moreover, in the next step, the collected data from Darakeh basin were described, analyzed, and interpreted through direct observations and field studies, and photography. The results relevant to gain an understanding of the region under the study as well as the results of field studies were analyzed through deduction-induction. After analysis of the indices, the relevant strategies and approaches were provided and they can be used as a pattern for other national and international rivers in similar circumstances.

Resilience in the face of flood disturbance

Resilience has received attention in recent years as a new approach in the face of environmental disturbances. Increased social, economic, and spatial vulnerabilities in cities and excessive destruction of the natural environment signifies resilience thinking (Masnavi, Gharai & Hajibandeh, 2018). The emergent dangers have significantly evolved in the international domain, such that the frequent perspective from an exclusive focus on decreased vulnerability has shifted to decreased vulnerability to natural catastrophes. According to this perspective, danger reduction plans must find ways to develop and strengthen the characteristics of resilience societies and focus on the resilience concept more and more. Upon increased environmental challenges in the contemporary era, this concept has been extended to other different sciences as well and has been defined and redefined by scholars in different disciplines. This approach is considered as a proper substitute for rigid and engineering approaches (Bahrami et al., 2019), such that resilience can be discussed as a concept relevant to the environment, or more specifically, a concept related to the systems (ibid.). For the first time, Holling (1973) has introduced the concept of resilience based on ecology and dynamic ecosystems. From his perspective, resilience can be defined as the potential to absorb the disturbances and prevent the disturbance of the whole system. After Holling, different scholars have attempted to develop and extend the concept of resilience. Alberti & Marzluff (2013) suggest that resilience is a combination of abilities, learning, adaptation, re-self-organization, achieving balance as well as absorption of disturbances. Folke (2016) also defines resilience as the system's potential in the face of disturbances and the potential to develop a system in the face of variations and disturbances. Thus, it can be argued that resilience is considered as a potential or flow to arrive at a conclusion. Besides, resilience helps adjustment until sustainability is achieved, such that lack of sustainability will prepare the grounds for the transition to a new equilibrium phase. That's while sustainability or lack of potential to change or adjustment is considered as a kind of non-resistance in this approach (Masnavi et al., 2018).
Accordingly, different authors have been working on resilience and its indices which are discussed in Table 1. Considering the frequency of indices in the literature, the indices investigated in this study are included in Table 2. The frequency of the study indices are as follows:
% 66 for redundancy, % 60 for diversity, % 40 for connection, % 40 for strength, % 27 for variability, % 27 for learning, and % 27 for self-organization. The former indices were among the ones with a high-frequency percentage and some other indices including autonomy, readiness, continuity, multi-functionality, reflexivity, effectiveness, modularity, and innovation have been rarely discussed in this study. Thus, some of the most influential indices on resilience thinking (e.g. redundancy, diversity, strength, connection, variability, learning, and self-organization) have been rarely discussed in this study. Resilience includes indices and characteristics which help a system a lot in the face of different environmental disturbances. These indices are numerous and the researchers in this field have mentioned only some of them. However, the authors of this study, have complied and described seven indices of resilience as the main ones based on the review of the related literature and Table 1. These indices are considered as the main characteristics of a resilience system. They include:

• Redundancy

Godschalk (2003) argues that redundancy refers to the plurality of similar components, such that the whole system wouldn't stop functioning in the case of one dysfunctional component being present. In other words, redundancy makes the systems capable of using trivial resources as an instrument for their own reproduction in a disturbance-laden environment (Linnenluecke & Griffiths, 2010). Therefore, multiple components or elements can lead to similar circumstances or support several functions (Ahern, 2011). Webb & Bodin (2008) suggest that redundancy in resilience thinking refers to "more than that".

• Diversity

Diversity is considered the most basic constituent of resilience (Bahadur Ibrahim & Tanner, 2010). Diversity refers to "a number or different functional components within a system

Table 1. Resilience indices cited by theoretician. Source: Authors

Resilience indices	Authors
Self-organization, redundancy, learning	Carpenter & Gunderson (2001)
Redundancy, diversity, effectiveness, independence, strength, association, variability, cooperation, self-organization	Godschalk (2003)
Diversity, variability, modularity, innovation, self-organization	Walker & Salt (2006)
Learning, redundancy, self-organization	Berkes, Colding & Folke, (2003)
Fluidity, reflexivity, connection, redundancy, multi-functionality	Davoudi & Strange (2009)
Strength, flexibility	Linnenluecke & Griffiths (2010) Wardekker, Jong, Knoop, Van der sluijs (2010)
Diversity, learning	Tyler & Moench (2012) Hassler & Kohler (2014)
Redundancy, diversity, multi-functionality, connection, variability	Ahern (2012)
Connection, strength	Eraydin & Tasan-kok (2013)
Diversity, redundancy	Hassler & Kohler (2014) Suárez, Gómez-Baggethun, Benayas & Tilbury (2016)
Diversity, learning, redundancy, self-organization	Folke (2016)
Variability, flexibility, redundancy, diversity, efficiency, strength, profitability, independence, connection	Feliciotti, Romice & Porta (2016)
Redundancy, diversity, efficiency, autonomy, connection, variability, strength, flexibility	Sharifi & Yamagata (2016)
Diversity, connection, redundancy, strength	Gharai et al. (2018)

Table 2. Resilience indices. Source: Authors.

Resilience indices	Definition of index	Reference
Redundancy	System redundancy is a characteristic that insures it against damages or failure through different components or paths which perform similar or supportive functions. This illustrates a kind of internal diversity.	Hassler & Kohler (2014), Sharifi & Yamagata (2016), Suárez et al. (2016), Wilkinson (2012), Walker & Salt (2006), Godschalk (2003), Folke (2006), Holling (1973), Carpenter & Gunderson (2001), Berkes (2007)
Diversity	The diversity of structural elements prepares the grounds for enhanced multi-functionality of the system and will extend the interaction among its several components. Diversity allows the system to maintain relative sustainability in different circumstances	Hassler & Kohler (2014), Sharifi & Yamagata (2016), Suárez et al. (2016), Godschalk (2003), Wilkinson (2012), Walker et al. (2004), Folke (2016)
Strength	The strength or potential of system elements and units to resist disturbances without any destruction within the system or losing performance is known as a resilience index as well.	Sharifi & Yamagata (2016), Eraydin & Tasan-K (2013), Bruneau, et al. (2003)
Connection	The structure of connections defines the contact points among elements as well as the locus and intensity of actions.	Feliciotti et al. (2016), Masnavi et al. (2018), Chelleri & Olazabal (2012), Marcus & Colding (2014), Ahern (2012), Allan & Bryant (2011)
Learning	The possibility of comprehending variation and disturbance based on past experiences	Tyler & Moench (2012) Godschalk, (2003), Carpenter & Gunderson (2001), Berkes et al. (2003), Bahadur, Ibrahim, & Tanner (2013), Folke, (2016)
Self-organization	System's resilience is dependent upon its capacity for re-self-organization because natural cycles involve re-self-organization	Carpenter & Gunderson (2001), Berkes (2007), Manyena (2006), Klein, Nicholls & Thomalla (2003)
Variability	Development within new paths or even the development of totally new paths	Folke (2016), Walker, Abel, Anderies & Ryan (2009), Gunderson & Holling (2002), Walker et al. (2004)

through which it can protect itself against different threats and damages (Godschalk, 2003). It also makes the system capable of variation or transformation to new methods and ways (Tyler & Moench, 2012). Thus, considering the multiplicity of components, a system takes on different and substitute approaches against pressures, shocks, disturbances, and dysfunctions (Ahern, 2011). Consequently, high diversity in different functional groups in a system can be effective in enhancing the system's resilience to a great extent (Holling, 1973; Carpenter & Gunderson, 2001; Folke, 2006).

• Strength

The System's strength is defined as its strength and resistance against external attacks or forces (Godschalk, 2003). Lu and Stead (2013) believe that the "system's power is determined in the light of its potential for carrying and absorbing the uncertainties" (Anderies, Walker & Kinzig, 2006). put strength as a concept for protecting some of the system's components against external dysfunctions and fluctuations. Resilience systems are resistant systems that rely on rigid protective structures (e.g. sea walls) that have been designed in a way emphasizing the resistance of a particular component to ensure its performance (Tyler & Moench, 2012).

• Connection

The connection index makes it feasible for making the intra-system accessible to all the elements within a system through communication infrastructures and increased connections (Feliciotti et al., 2016). The structure of connections strengthen the correlation between the components and finally results in a cohesive network or corridor (Masnavi et al., 2018). Some of the authors favor low connection and some others favor high connection. The reason is that high connection will result in fast propagation of remission after a situation of crisis and low connection will reduce the scattering of dysfunctions as well (Chelleri & Olazabal, 2012; Marcus & Colding, 2014).

• Learning

In recent ecological studies, social-ecological systems, crises management, and urban sustainability, the necessity of learning in a system have been emphasized for resilience against disturbances (Adger, Hughes, Folke, Carpenter & Rockström, 2005; Berkes et al., 2003; Tyler & Moench, 2012). Learning capacity is "the potential to domesticize past experiences, prevention of repeated failures, innovation for performance improvement, and learning new skills" (Tyler & Moench, 2012). Learning makes it possible to perceive variations based on new experiences (Gunderson & Holling, 2002), while these experiences can be either positive or negative (Macrae, 2010, Müller, 2011).

• Self-organization

The system's resilience is positively correlated with its capacity for its re-self-organization because natural cycles include renovation and re-organization (Holling, 2001; Berkes, 2007). Adoption processes also originate from the system's self-organization capacity which is basically related to tolerance and variation resistance capacity (Folke, 2006). System dynamicity depends upon its own adjustment potential after tolerating dysfunctions incurred on the system's self-organization capacity (Folke, 2006). Besides, the system's self-organization follows temporal and spatial measures (Gunderson & Holling, 2002; Folke, 2006). Tyler & Moench (2012) indicated that self-organization prepares the grounds for independent responses to climatic changes and other dysfunctions.

• Variability

Capacity variability is the capacity to develop a completely new system when the existing ecological, economic, and social structures become indefensible (Walker, Holling, Stephen, Carpenter & Kinzing, 2004). This index increases the system's resilience and sustainability (Folke et al., 2010). Folke (2006) suggests that variability interferes with the development of new paths as well as the development of a completely new system. On the contrary, adoption refers to human attempts directed toward maintaining development within the same paths.

Principles and criteria governing resilience landscape design in the face of flood

The resilience characteristics are indeed the indices of resilience thinking through which a system will remain stable in the face of uncertainties and disturbances; however, the direct application of these characteristics for planning and designing a system is impractical. Thus, for designing disturbance-laden environments, particular strategies are required. Researchers have not directly referred to such strategies; however, the authors of this study extracted strategies to measure these indices based on the definitions and characteristics provided for these indices. They are included in Table 3. In fact, each of these strategies is a combination of several elements that have been comprehended by the authors. Using the information in Table 3 and the analytical induction technique, the authors of this study compiled the existing strategies in popular indices of resilience thinking in theories developed by the authors in this field in the following table (Table 4).

Resilience design and planning of the river Darakeh

The river Darakeh is considered as one of the main five connection channels connecting north to the south and exists in linear and extended form. It is regarded as one of the most precious rivers in Tehran and as one of the main natural corridors located in Alborz Mountain (Bahrami, 2018). This river is endangered by floods just as other urban rivers located in Tehran province of Iran and its environment, social and economic infrastructures are endangered (Table 5). To reduce flood risk, this river has come under attention within the comprehensive plan of 1978, 1990, and 2006. The comprehensive plans of 1978 and 1990 were limited to a one-dimensional, rigid, and engineering perspective and underestimated the value of this natural corridor to a corridor for the expulsion of floodwater (Fig. 1). However, contrary to the comprehensive plans of 1978, and 1990, the comprehensive plan of 2006 paid due attention to the natural value of urban rivers alongside global changes, such that a new approach compatible with river circumstances can be applied in crises

Table 3. Extraction of design strategies from the resilience indices' definitions. Source: Authors.

Resilience indices	Definition of indices in different references	Extraction of strategies	The method applied for strategies extraction
Redundancy	Multiple response paths within a system will prepare the grounds for the system's partial failure in a system without its total collapse (Rockefeller Foundation, 2009).	Multiplicity of spatial components	Direct comprehension of the definition
	Multiple elements or components may prepare similar conditions or support the system's functions (Ahern, 2011).	Multiplicity of functional components	Direct comprehension of the definition
	Increased per capita green space and public open spaces (Chelleri & Olazabal, 2012).	Multiplicity of biological components	Direct comprehension of definitions
Diversity	Diversity referring to the creation of multiple spaced with different functions in the space (Bahrami et al., 2019).	Spatial diversity	Direct comprehension of the definitions
	Structural diversity and structuring urban elements (Gharai, 2018). Functional diversity and functional groups within a system (Folke 2006; Holling 1973; Carpenter & Gunderson, 2001).	Biological diversity	Summarizing the definitions and comprehending their similarities
	Diversity in resilience refers to ecosystem diversity, biodiversity, and diversity of natural resources (Bahadur et al., 2010).	Biodiversity	Direct comprehension of the definitions
Strength	Strength and potential of the system's elements and subsystems to resist against any degree of disturbance (Gharai et al., 2018).	Strength of human-made components	Analytical comprehension of definitions
	Resilience systems are basically resistant systems relying on rigid protective structures, being designed in a way that emphasis is put on the strength of particular components (Tyler & Moench, 2012).	Strength of natural components	Analytical comprehension of definitions
Connection	Smaller urban blocks will result in increased contact and exchange points among the elements and facilitate the mobility of people and goods (Bently, 2010; Jacobs, 2007).	Minority and penetrability	Analytical comprehension of definitions
	The continuous relationship among system components leads to higher system resistance (Bahadur et al.,2010).	Continuity of design components	Direct comprehension of definitions
	There is a high degree of connection among different elements of a system in the heart of affirmative resilience (ibid.).	Strengthening the spatial relations	Direct and analytical comprehension of definitions
Learning	Different types of knowledge contribute to higher learning potential (Berkes, 2007).	Knowledge level	Direct comprehension of definitions
	Learning from experiences is another characteristic of resilience systems (Carpenter & Gunderson, 2001).	Experience from past events	Summarizing and comprehending the similarities between definitions
	Studying the success factors of past communities in the face of unpredicted catastrophes (Berkes, 2007).		
	A system requires learning to exercise resilience against shocks (Adger et al., 2005; Antrobus, 2011; Berkes et al., 2003; Twigg, 2007; Tyler & Moench, 2012).	Awareness of the resources	Analytical comprehension of definition
Self-organization	System's resilience is positively correlated with its own re-self-organization potential because natural cycles involve some form or re-organization (Holling, 2001; Berkes, 2007).	Biological self-organization	Direct comprehension of definitions
	Capacity and potential of the system's main components (e.g. gathering) for achieving a degree of self-sufficiency and self-organization after any disturbance)Carpenter & Gunderson, 2001; Folke et al., 2003).	Social self-organization	Direct comprehension of definitions
Variability	Interaction and cooperation from domestic knowledge (Manyena, 2006; Mayunga, 2007; Mwangi & Ostrom, 2009; Dovers & Handmer, 1992; Berkes, 2007).	Increased knowledge, potential, and skill of indigenous individuals and experts within a system	Direct comprehension of definitions, Summing up the definitions
	Variability, varying the development to new paths and even developing another path (Folke, 2016).	Diversity and multiplicity of design components	Direct comprehension of definitions

(Alehashemi, Bagheri & Akhavan, 2015). However, despite these plans and designs, this river is vulnerable to floods. In addition, the natural structure of River Darakeh has changed due to multiple flood control channels and terracing the bed's river and therefore its vegetation has been reduced, its water penetrability has been reduced and the amount of runoff has been increased as well. Therefore, besides flood danger, biological and ecological components of River Darakeh are being destroyed (Aslani & Mehdipour, 2015). Consecutive floods being occurred in 1987, 1998, and April 2019 confirm the same argument that flood risk threatens River Darakeh and attests to the insufficiency of structural and construction plans for flood management. The application of resilience thinking in designing and planning the river Darakeh gains significance due to the occurrence of multiple floods and their ecological consequences. Besides, due to evidence referring to the existence of a disturbance-laden environment in this river and components for facing these environments in resilience theory, it seems that this planning and design approach may be of great help to reduce the risk of flood and increase the recovery of the river's natural ecosystems. Thus, based on resilience strategies and indices, the planning and design of the river Darakeh in the face of flood disturbance will be as follows:

- **The impact of "Redundancy" component in resilience planning and design of the river Darakeh**

Redundancy refers to a degree of intra-system diversity which makes the whole system resilient in the face of different disturbances (Meerow & Stults, 2016; Marcus & Colding, 2014). This index includes three levels in resilience-laden systems, namely, 1) frequency of spatial components; 2) frequency of functional components, and 3) frequency of

Table 4. Strategies extracted from resilience indices. Source: Authors.

Resilience index	Strategies	Reference
Redundancy	- Multiplicity of spatial components - Multiplicity of functional components - Multiplicity of biological components	Hassler & Kohler (2014), Sharifi & Yamagata (2016), Suárez et al. (2016), Wilkinson (2012), Walker & Salt (2006), Godschalk (2003), Folke (2006), Holling (1973), Carpenter & Gunderson (2001), Berkes (2007)
Diversity	- Spatial diversity - Functional diversity - Biodiversity	Hassler & Kohler (2014), Sharifi & Yamagata (2016), Suárez et al. (2016), Godschalk (2003), Wilkinson, (2012), Walker et al. (2004), Folke (2016)
Strength	- Strength of human-made components - Strength of natural components	Sharifi & Yamagata (2016); Eraydin & Tasan-Kok (2013), Bruneau et al. (2003)
Connection	- Minority and penetrability - Continuity of design components - Strengthening spatial connections	Feliciotti et al. (2016), Masnavi et al. (2018), Chelleri & Olazabal (2012), Marcus & Colding (2014), Ahern (2012), Allan & Bryant (2011)
Learning	- Knowledge level - Experience from past events - Awareness of resources	Tyler & Moench (2012) Godschalk, (2003), Carpenter & Gunderson (2001), Berkes et al. (2003), Bahadur et al. (2013), Folke (2016)
Self-organization	- Self-organization of biological resources - Social self-organization	Carpenter & Gunderson (2001), Berkes (2007), Manyena (2006), Klein et al. (2003)
Variability	- Diversity and multiplicity of design components - Increased knowledge and skill of indigenous people and intra-system experts	Folke (2016), Walker et al. (2009) Kirmayer, Dandeneau, Marshall, Phillips & Williamson (2012), Gunderson & Holling (2002), Folke et al. (2009), Walker et al. (2004)

Table 5. Darekeh flood report. Source: Authors.

Darakeh flood	Descriptions	Reference
1986	The highest flow rate in the river Darakeh is for 1986. High flow rate fluctuation increases the risk of the flood as well.	Ghanavati et al. (2017)
1987	The chairman of the flood control office suggested that the serious damages incurred by the flood on August 1987 to parts of the capital and its infrastructures were due to precipitation and sudden flood and declared Darakeh basin as one of the basins with a high flood risk.	Borna News Agency (2020)
1998	Considering the structural and construction approach for the management of late 1980s flood, the flood that occurred in 1988 refers to the insufficiency of the engineering plan provided by consultant engineers.	Sabokro (2019)
2019	Considering the flood history of this basin and the unfavorable climatic conditions and the emphasis made by Tehran Province's crisis management body to prevent any possible catastrophe, all of the public spaces have been shut down in April 2019 for prevention of human gathering and depot.	Eskan News (2019)

Fig. 1. Terracing and construction of channels on the river Darakeh. Source: Sabokro, 2019.

biological components. The frequency of both spatial and functional components in the system of the River Darakeh refers to the frequency of a subsystem such as bridges, landscapes, houses, paths, etc. In addition, the frequency of biological components within this system entails the number of agricultural lands, gardens, and different branches of the River Darakeh, such that in case any of the gardens located in Darakeh basin will confront flood disturbance, another garden with the same function, as of the previous gardens, will be available within the system.

• The Impact of "Diversity" component in resilience design and planning of river Darakeh

The diversity function in a resilience system refers to the variety of its different subsystems which makes a system sustainable in the face of different disturbances and dysfunctions (Bahrami et al., 2019). This index is measurable in the planning and design of River Darakeh in three different levels, namely spatial diversity, functional diversity, and biodiversity. The spatial and functional diversity in River Darakeh's resilience system entails the design and planning of different spaces based on the water flow rate, such that different spaces such as bridges, houses, landscapes, stations, paths, etc. will be planned according to water flow rate and based on the status of the river (in terms of drought or high water level). The biodiversity of the resilence system of the River Darakeh refers to the existing diversity of gardens, agricultural lands, and branches, and biological paths. Thus, different agricultural lands with different products alongside the River Darakeh must be planned and designed in a way that flood disturbance won't be capable of diminishing all agricultural lands and gardens. Also, the recovery of older branches of River Darakeh which have been diminished as a result of channel construction will contribute to higher biological and animals along this river.

• The Impact of "Strength" component in resilience planning and design of river Darakeh

Higher system strength makes it capable of resisting the disturbances without any destructive effect on the system or losing its functions which will result in higher resilience by itself (Bruneau et al., 2003; Lu & Stead, 2013). This index is applied in resilience planning and design or River Darakeh in two different levels, i.e. the strength of human-made components and the strength of natural components. In terms of using this index in the planning and design of River Darakeh, one can refer to the strength of human-made components including communication roads, bridges, landscapes, houses, etc. Also, the strength of natural components refers to the strength of the river's natural elements including land's slope, trees, stabilization of river's ridges, etc. in the face of flood disturbance which will result in stability by themselves. Moreover, the use of penetration element against the rigidity of design components, will enhance their strength against the incoming forces and contribute to higher resilience; that's because penetrability, such as penetrability of communication roads and development of wetlands for the absorption of runoffs plays a significant role in enhancing biological diversity and creating a living environment for animals and creatures. This biodiversity can depreciate part of the incoming force within itself and will reduce the impact of force and the incurred damages.

• The impact of "Connection" component in resilience planning and design of river Darakeh

Connections increase the contact area among different components which will result in heightened resiliency and coherence by itself (Gharai et al., 2018). In this plan, the connection index is to be investigated in three different levels of 1) continuity of design components, 2) strengthening the spatial connection, and 3) minority and penetrability. To apply the connection index, the continuity of communication channels must be emphasized leading to higher accessibility in a short period. Moreover, higher accessibility and increased internal connection within the system will result. Furthermore, penetrability is considered as another design variable of this index, facilitating the communication and exchange between different components and mobility. It also increases the contact area and will finally contribute to higher spatial connection and resilience in the face of disturbances.

• The impact of "Learning" component in resilience planning and design of river Darakeh

Learning is considered as one of the main indices of a resilience system, through which strategies can be proposed for overcoming future disturbances of a system

(Bahrami et al., 2019; Godschalk, 2003). In the planning and design of River Darakeh, this index can be studied in three different levels, namely, 1) increased knowledge, 2) increased experience from past dysfunctions, and 3) increased knowledge of resources and information. To increase knowledge level, we can increase Darakeh village inhabitants" knowledge regarding the flood disturbance. Moreover, expert opinions and advice can be used to increase experience from past disturbances. Besides, we can rely on historical mas, articles, historical books, indigenous people's knowledge, and expert knowledge for increased knowledge from information resources. Finally, the establishment of stations in different parts of River Darakeh leads to sufficient knowledge and information regarding the river's behavior in the face of flood disturbance.

• The impact of "Self-Organization" component in resilience planning and design of river Darakeh

Self-organization refers to the dynamicity of the environment and ecosystems which are always variable and not stable. Therefore, a resilience system always attempts to comply with different conditions of the surrounding environment (Folke, 2016; Berkes, 2007). In this particular design and planning, the self-organization index can be measured in two different levels, i.e. 1) self-organization of biological resources and 2) social self-organization. With regard to the self-organization of biological resources, one can refer to the development of a balance between aqueous resources between drought and non-drought seasons, such that water storage during autumn and spring, in which water flow rate is higher than in other seasons not only water flow rate would be decreased, but also they will be stored for summer. Moreover, social self-organization refers to domestic self-sufficiency, such that the rural inhabitants alongside River Darakeh acquire sufficient knowledge and skill for controlling and reducing flood disturbance.

• The impact of "Variability" component in resilience planning and design of river Darakeh

As soon as the structures within a system become indefensible in the face of disturbance, variability, as a resilience index will lead to increased resilience through the development of a new path inside the system (Walker et al., 2004). In this planning and design approach, the variability index is discussed in two different levels, i.e. 1) variety and multiplicity of design components, 2) increased knowledge and skill of indigenous people about this system. In terms of applying relevant strategies to this index, one can refer to the environment's potential for repairing itself through the development of different communication channels to be substituted for damaged paths, the use of biodiversity such as different gardens, increased green space infrastructures, etc., such that the system attempts to maintain stability and achieve a new equilibrium point in the face of shocks.

Results

The River Darakeh, as one of the main natural components of Tehran, has been always the focus of study for landscape architectures, civil engineers, ecologists, and citizens. Despite different plans based on Tehran city's comprehensive plan, this river has been vulnerable in the face of flood disturbance in some seasons of the year. This study proposes a comprehensive resilience plan based on particular features of the River Darakeh. According to different indices of resilience planning, a total number of seven indices have been selected considering the frequency in different studies being conducted. Since the direct application of these indices is impossible for flood-disposed places, the recommended strategies and solutions for disturbance-laden environments, extracted from the literature were included in Table 4. Thus, considering the evolutionary nature of this trend, the recommended approaches and solutions for resilience planning of the area in the face of flood disturbance and recovery of its natural and ecological structure are included in Table 6.

Conclusion

This study was an attempt to recommend solutions for the management and planning of the River Darakeh based on indices and strategies extracted from resilience thinking. In this study, resilience planning of the River Darakeh has been proposed through relying on seven indices of resilience thinking, these indices include redundancy, diversity, strength, connection, learning, self-organization, and variability, accordingly, the redundancy index refers to multiple components and subsystems of the River Darakeh. It entails the multiplicity of spatial, functional, and biological components. In case any of these subsystems would be diminished as a result of the flood, another system would substitute it. Diversity index includes different strategies including spatial, functional, and biological. According to this index and its strategies, the development of multi-functional spaces based on water flow rate in different seasons of the year, planning different spaces including landscapes, bridges, communication channels, and various gardens and agricultural lands are desired. The strength index refers to the increased potential of components of subsystems of the River Darakeh to resist the flood. This index helps a lot in maintaining the system's structure in the first moments of disturbance. The connection index in this system refers to increased communication among the subsystems. Thus, higher emphasis is put on further communication between all design components including accessibility, communications within public static spaces and dynamic mobility spaces, and the design of public and static spaces and its combination with dynamic mobile paths. The learning index in the resilience system of the river Darakeh raises the awareness of rural people and experts regarding the river's behavior in different seasons of the year and its hidden characteristics. Therefore, this index includes different dimensions including higher domestic knowledge conceding flood in the river Darakeh through holding workshops and teaching courses for domestic people, the use of domestic experts to increase awareness and knowledge regarding past flood events, and the use of different resources for increasing knowledge and information about River Darakeh. The self-organization index of the river River Darakeh refers to the self-organization of social and biological resources. Accordingly, in River Darakeh's resilience system, social self-organization refers to domestic individuals' potential to recover after each disturbance and turn their environment into a secure and environmental-friendly space. In addition, biological self-sufficiency refers to the ecological balance between drought and flood seasons. Finally, the variability index in the resilience system of the river Darakeh helps a lot in the system's recovery after the disturbance. Through the development of multiple paths, this index makes the system enter a new phase to remain stable even after the flood event. This comprehensive plan which entails different environmental and social dimensions, including ecological, domestic, historical, and cultural potentials of the river Darakeh can be a good substitute for flood control channels and terracing the river's bed. Flood control channels are considered as a rigid approach against nature and natural forces are not a good solution for restraining flood. This, the new resilience approach emphasizing different dimensions of the river and their social and environmental conditions, can be considered as a good substitute for this rigid approach. Finally, this planning which is the result of resilience thinking directs landscape planning of urban rivers including the river Darakeh toward a comprehensive plan.

Table 6. Resilience planning and design of River Darakeh based on resilience thinking. Source: Authors.

Resilience index	Planning strategies	Recommended solutions
Redundancy	Multiplicity of spatial components	Abundance of subsystems
	Multiplicity of functional components	Multiplicity of bridges, sights, houses, paths, public and recreational spaces
	Multiplicity of biological components	Multiplicity of agricultural lands, gardens, and branches of the river Darakeh
Diversity	Spatial diversity	Development of spaces with different applications, design, and planning based on water flow rate, planning based on different seasons of the year
	Functional diversity	Functional spaces including bridges, communication channels, houses, sights, and stations
	Biological diversity	Diversity of gardens, agricultural lands alongside the river Darakeh, recovery of river branches and biological paths
Strength	Strength of human-made components	Strength of communication channels including roads, bridges, landscapes, and houses
	Biological diversity	Increased land slope's strength, and stabilization of river ridges
Connection	Minority and penetrability	Increased connection and contact points such as bridges, connection paths, design of public and static spaces, and its combination with mobilized dynamic paths
	Continuity of design components	Increased accessibility, increased number of internal connections through the development of spatial joints
	Strengthening the spatial connection	Sum of the whole static public communications and dynamic mobility facilitates the exchange between components and current.
Learning	Knowledge level	The use of public media, holding workshops and courses
	Experience from past events	Use of public and indigenous experts; experiences through interview or questionnaire
	Awareness of resources	The exploitation of historical maps, papers, historical books, the knowledge base of rural people and experts, the establishment of stations in different parts of the river, and getting informed about River Darakeh's behavior in the face of flood disturbance
Self-organization	Self-organization of biological resources	Balancing the aqueous resources between drought and non-drought seasons, storing water during autumn and spring
	Social self-organization	Domestic self-sufficiency, sufficient knowledge, and skill of domestic inhabitants and rural people for controlling and educing flood disturbance
Variability	Variety and multiplicity of design components	Use of environmental potentials, different communication channels, application of biological diversity, and increased green space infrastructure
	Increased knowledge and efficiency of domestic inhabitants and experts within a system	The use of public media, holding workshops and courses

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