

Urban Resilience Assessment Using Hybrid MCDM Model Based on DEMATEL-ANP Method (DANP)

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Abstract

In fact, the views of world communities have shifted from a focus on reducing vulnerability to increasing resilience in the event of a crisis. The present study used GIS-based DANP model to investigate the resilience of Tehran districts to hazards. First, the influencing criteria on resilience were selected in four dimensions using Delphi method. Then, a DEMATEL model followed by an ANP were applied to define the internal relationship between the criteria. Next, the GIS overlay was performed to give visual outputs. DEMATEL results showed that disasters and natural hazards in the environmental dimension, urban infrastructure in the physical dimension, and employment rate in the socio-economic dimension were the most important criteria which affected urban resilience. Additionally, 54.7% of the total urban area was categorized in very-low to moderate resilience classes, needing serious attention. This study provides fresh insights for urban planners to know the cause-and-effect relations between dimensions and criteria, to best deal with the resilience.

1. Introduction

Over the last few decades, the world population has grown exponentially (Choi and Labhsetwar 2020). Approximately 50% of the population of the world live in urban areas (Newman 2009). Cities provide a safe environment for economic activity, opportunity, and creativity. However, several hazards have posed a threat to this security by creating crises and causing vulnerability in the structure and function of cities (EC 2010). The vulnerability of a city leads to irreparable damage to physical, environmental, social, economic, and institutional dimensions, which can threaten the foundation of a city (Fatemi et al. 2020; Formetta and Feyen 2019). Although disaster risk management has resulted in actions to avoid new hazards and minimize and manage current hazards, disaster risk management combined with strengthening urban resilience is now recognized as a proper practice for preventing and responding to the consequences of a disaster (Benson 2016; UNDRR 2019). Therefore, disaster risk management along with sustainable development perspectives seek to create resilience among communities and individuals in response to hazards (Uitto and Shaw 2016; Benson 2016). In this view, it is essential to perform strategies for urban resilience which can decrease disaster hazards by changing challenges to opportunities (Moraci et al. 2018).

Resilience is one of the significant principles of sustainable development (Liang and Li 2020). Resilience, originally meaning as jumping back and bounce-back (original meaning from the Latin “resilire”, “resalire”, “resilio,”) and to the ability of recovery and restoration (Annarelli et al. 2020). Resilience mostly focuses on the bounce-back of the system to the equilibrium over time after a disruption (Döring et al. 2015). There are various descriptions of resilience in previous studies. Holling (1973) first used the word ‘resilience’ and defined it as a measure of the persistence of systems and their ability to absorb change and disturbance and maintain the same relationships between populations or state variables. Wagner and Breil (2013) that resilience is the general capacity and ability of a system to resist pressure, survive, modify, and bounce back from a disaster. In addition, Rose (2009) considered resilience as the ability to maintain function in crises. Additionally, Martin-Moreau and Menascé (2018) stated that the resilience of

a system is its ability to reconstruct itself and recover its balance after being disordered. In this way, resilience describes not only the capacity to resist but also the ability to recover after a shock and return to the previous state. The common point of all these definitions is the reversibility of capacity, adaptation, disaster recovery, absorption, resilience, and survival, which could be applied to deal with disruption and adaptation of society. These disorders include crises, stresses, and shocks.

The concept of resilience has been constantly developing and could refer to resilience for adapting in the face of climate change (Rajkovich and Okour 2019), hazard risk management and resilience (Etinay et al. 2018; Galderisi and Treccozi 2017), resilience in energy and environmental security (Keskinen et al. 2019), urban resilience (Wang et al. 2018; Mohamadzadeh et al. 2020), and social-ecological system resilience (Li et al. 2020; Garmestani et al. 2019). The review of the research literature indicate that resilience is a comprehensive concept with several dimensions. Moving towards a comprehensive definition of this concept for considering all the influencing factors can eventually lead to resilience in systems. Therefore, it is highly important to determine the factors which influence urban resilience, which can help successful planning and improve adaptation and management of changing conditions.

Tehran, as the largest metropolis and capital of Iran with more than 8.9 million of the inhabiting population in Tehran, suffers from widespread pressures on natural resources and ecological life support systems due to rapid population growth (Statistical Center of Iran 2016). This issue has led to environmental, economic, social, and cultural problems which pose serious challenges for planners and decision-makers in strategic urban planning. Some of these challenges in Tehran megacities include decreased capacity to absorb contaminants, imbalance between population and urban infrastructure, high resource consumption, intensive land use, and inequalities of urban districts in urban per capita. The present study aims to present methodical research to assess the criteria affecting urban resilience in Tehran metropolis. Considering the fact that several complicated and interrelated factors influence assessing urban resilience, this study applies a hybrid MCDM approach by integrating the Experimental Lab and Decision Evaluation (DEMATEL), and Analytic Network Process (ANP). In the DEMATEL-based ANP (DANP) method, the dependent relationships between the criteria and the relative importance of each criterion are determined. More specifically, the present study mainly aims to:

- To construct a network structure model for each criterion and dimension.
- To investigate the relationship between the effective criteria.
- To determine the important criteria and measure the weight per criterion.

1.1. Theoretical framework

Resilience, as a dynamic process relying on the inherent and adaptive capacities of a society, helps decision-makers deal with unforeseen shocks or stresses by developing strategies and action plans (Moghadas et al. 2019). Resilience is a multi-dimensional approach. Thus, assessing resilience structure should ideally consider all various dimensions and criteria of an urban system to improve the integrity and content validity of the assessment system (Sharifi and Yamagata 2016). In this study, four

dimensions of resilience are considered based on theoretical and experimental principles: social-economic, institutional, physical, and environmental dimensions. The first component is the social and economic dimension. Social resilience obtains from differences in social capacity between communities. In other words, it expresses the capacity of social groups to recover and be reversible in response to natural disasters (Keck and Sakdapolrak 2013; Kwok 2016). In economics, resilience is the inherent response and adaptation of people and societies to risks, which can enable them to decrease the cost of probable damages to make financial recovery possible (Rose and Liao 2005; Hallegatte 2014). The second component is the physical dimension which includes assessing the community response and post-disaster recovery capacity. The physical system must be able to continue to play its role and function under the pressure of danger. A city without a resilient physical structure would damage greatly by unforeseen stress and shocks (Cutter and Burton 2010). The third component is the institutional dimension which includes features related to risk reduction and planning. Here, resilience is affected by the capacity of communities and the use of local people to reduce risks for creating links within an organized community and improving and protecting social systems in a community (Godschalk 2003). The environmental dimension of resilience concerns paying attention to issues such as environmental pollution caused by human activities and reducing the potential to absorb pollutants in urban systems (Cutter and Ash 2014; Moghadas et al. 2019). It is worth noting that each of the socio-economic, institutional, physical, and environmental dimensions f. Table 1 and Fig. 1 present the dimensions, criteria, and sub-criteria which affect resilience based on the literature review.

Table 1
The criteria effective in urban resilience assessment

Criteria	Literature
Disasters and natural hazards	Xu et al. (2020); Alizadeh & Sharifi (2020)
Water resources	Roach et al. (2018); Li et al. (2016)
Environmental pollutants	Xiong et al. (2019); Juan-Garcia et al. (2017)
Topography	Lawrence et al. (2020); Shim & Kim (2015)
Urban infrastructure	Tabibian & Rezapour (2016); Ongkowitzo & Doloi (2018)
Land use	Pourahmad et al. (2019); Javari et al. (2021)
Green space	Ni'mah & Lenonb (2017); Liu et al. (2020);
Employment rate	Tabibian & Rezapour (2016); Kammouh et al. (2019)
Population and education	Newport & Jawahar (2003); Chou & Wu (2014)
Health status	Bhandari & Alonge (2020); Thomas et al. (2013)
Insurance type	de Vet, E., & Eriksen (2020); Surminski et al. (2016)

2. Materials And Methods

2.1. Study area

Tehran as the capital of Iran is one of largest metropolises in the world. Official estimates indicate that 8.5 million people live in Tehran. Tehran metropolis is located between the latitudes of 35° 36' to 31° 44' N and the longitudes of 51° 17' to 51° 33' E. Urban is divided into 22 districts, 123 regions, and 374 neighborhoods (Fig. 2). Some statistics related to these districts are shown in Table 2.

Table 2
Statistics related to the municipal Districts of Tehran

District	Area (ha)	Population	District	Area (ha)	Population
1	3453	493889	12	1356	240909
2	4956	692579	13	1388	253054
3	2938	330004	14	1456	489101
4	7243	917261	15	2845	659468
5	5901	856565	16	1645	267678
6	2144	250753	17	827	278351
7	1537	312002	18	3785	419249
8	1324	4250044	19	1149	255533
9	1955	174115	20	2028	367600
10	806	326885	21	5196	186319
11	1187	308176	22	6140	175398

2.2. Identifying the criteria

Resilience assessment is a multi-criteria decision-making approach which evaluates resilience in different dimensions. To assess the degree of urban resilience, it is essential to identify the factors and crises which make urban vulnerable to natural and anthropogenic disasters. Therefore, it is necessary to pay careful attention for determining an appropriate and clear set of criteria for assessing urban resilience. In this study, a questionnaire with 53 criteria in four dimensions was designed according to a comprehensive literature review, experts' opinions, local conditions, and data accessibility. The Delphi technique was used to screen the selection criteria.

The Delphi method is a process for reaching agreement on a matter between a panel of specialists (Hsu and Sandford 2010). The panel in this research included 20 experts including professional experts in government organizations and academic experts from various geographical locations. Table 3 shows the demographic information of the survey participants. Past research has shown that two or three rounds

are sufficient to achieve a reasonable result in the Delphi method. The number of rounds depend on the level of consensus on all items, whenever 70% of the experts reached an agreement (Xiaorong et al. 2020). In this study, the Delphi technique was implemented in two rounds. The initial screening was conducted to determine a list of criteria which could be used for assessing resilience. In this step, the criteria with arithmetic means of less than 3 were eliminated. In the second screening, criteria and sub-criteria were approved and respondents were presented with a 5 level Likert scale ranging from 'Strongly disagree' to 'Strongly agree' and were asked to rate the importance of the criteria for urban resilience.

Table 3
Information related to the survey participants

Characteristic		N	Percentage
Gender	Male	16	80
	Female	4	20
Age	30–40	10	50
	40–50	4	20
	More than 50	6	30
Education	Bachelor's degree	9	45
	Master's degree	8	40
	PhD	3	15
Job classification	National Disaster Management Organization	6	30
	Management and Planning Organization	4	20
	University Professors	3	15
	Municipality Organization	7	35
Work experience	5 to 10 years	6	60
	10 to 20 years	10	50
	More than 20 years	4	20

Accordingly, four dimensions, 11 criteria, and 32 sub-criteria were employed for assessing urban resilience (Table 4). The four influential dimensions are environment, socio-economic, physical, and institutional aspects. The eleven criteria include disasters and natural hazards, water resources, environmental pollutants, topography, urban infrastructure, land use, green space, employment rate, population and education, health status, and insurance type.

Table 4
Criteria affecting urban resilience

Dimension	Criteria	Sub-criteria	
Environment (A)	Disasters and natural hazards (A1)	Percentage of critical infrastructure vulnerabilities in the event of a natural disaster (A1-1)	
		The degree of vulnerability of infrastructure to hazards (A1-2)	
	Water resources (A2)	Per capita water consumption per person (A2-1)	
		Surface water quality (A2-2)	
	Environmental pollutants (A3)	The average concentration of air pollutants (PSI) (A3-1)	
		The amount of urban wastewater production per thousand people (A3-2)	
		The amount of waste produced per person per day (A3-3)	
	Topography (A4)	Slope percentage (A4-1)	
		Elevation (A4-2)	
	Physical (B)	Urban infrastructure (B1)	Access to urban facilities (B1-1)
Passages, bridges, tunnels (B1-2)			
Access to fire stations (B1-3)			
Access to public transport (bus, taxi, subway) (B1-4)			
Access to medical centers (B1-5)			
Land use (B2)		Number of educational centers (B2-1)	
		Number of shopping centers (B2-2)	
		Number of residential centers (B2-3)	
		Worn-out texture rate (B2-4)	
		Antiquity of historical monuments (B2-5)	
Green space (B3)		Green space area (B3-1)	
		Green space density (B3-2)	
Socio-economic (C)		Employment rate (C1)	The employment rate (C1-1)
			Poverty line (C1-2)
		Population and education (C2)	Population density (C2-1)
	Urban migration rates (C2-2)		

Dimension	Criteria	Sub-criteria
	Health status (C3)	Literacy rate - general education (C2-3)
		Life expectancy (C3-1)
		Mortality rate (C3-2)
		Number of hospitals per 10,000 people (C3-3)
	Insurance type (C4)	Accident Insurance Percentage (C4-1)
Institutional (D)		Citizen education (D1-1)
		Existence of crisis management centers (D1-2)

2.3. Spatial analysis using GIS

Each criterion should be provided, collected, and scrutinized as a map layer in a GIS-based environment. For this purpose, the following GIS analytical techniques were used:

- Data and statistics for economic, health care, demographics, economic partnership, education, land use type, and consumption patterns were obtained from the Management and Planning Organization of Iran (MPO).
- Topographic indicators, roads, infrastructure, land use, and green space were gathered from the National Cartographic Center of Iran (NCC).
- Disasters and natural hazards criteria were gathered from the National Disaster Management Organization (NDMO).
- Data for the environmental and water resource criteria were collected from the Department of Environment and Water Resources Management Organization (WRMO) of Tehran Metropolis, respectively.

Finally, all vector layers were converted to raster format with a 30 m spatial resolution to apply GIS-MCDA functions. All layers were standardized to different measuring scales. This standardization was based on the cost and benefits context of the criteria, which could minimize or maximize the criteria based on their values and their significance for assessing sustainability (Mohamadzadeh et al. 2020). The Z-score method was used to standardize the criteria on a scale of 1–9. Next, the criteria weights were measured on different importance of criteria. The DANP approach was used to calculate the weights of the criteria. DANP is a combined model of Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP) technique (Chen et al. 2010; Azarnivand and Chitsaz 2015). In this study, the DEMATEL model was applied to evaluate the internal relationship between the criteria, and ANP was employed to assign the weights. Then, the Weighted Overlay technique was utilized to overlay the layers. Finally, the natural break classification was used to classify the resilience layer into three classes: low, moderate, and high. Figure 3 shows the schematic flowchart of the urban resilience assessment in Tehran metropolis.

2.4. DEMATEL-based Analytic Network Process (DANP)

The DANP is a decision support tool which can sufficiently provide relationship and interdependence between various subjects to facilitate problem-solving (Hsieh et al. 2017; Chiu et al. 2013). This model can verify the interdependence of variables and attributes and build a relationship which reflects characteristics with an essential system and evolutionary trend (Chiu et al. 2013; Liou, et al. 2012). DANP is a hybrid Multiple Criteria Decision Making (MCDA) which combines the DEMATEL and the ANP (Liu et al. 2014). DEMATEL solves the problem of influencing factors within a multi-factor interleaving system (Uygun et al. 2015). By using graph theory and matrix tools, the DEMATEL method can calculate the cause and effect of each factor and convert the relationships among the factors into a structural model to visually represent the interdependence among them. The DANP model adopts a composite influence matrix, instead of normal pairwise comparison matrices within the ANP, to discover the weight of each factor (Wang et al. 2018). This model has been applied in many studies (e.g., Gigović et al. 2017; Wang et al. 2018). The main steps of the DANP method are as follows:

2.4.1. DEMATEL method

Step 1

The five-point scale is used to pairwise comparisons by considering the level of impacts of particular dimensions. The measurement criteria of 0, 1, 2, 3, and 4 are applied for indicating no, very low, low, high, and very high influence, respectively (Tseng and Lin 2009).

Step 2

The direct-influence matrix is created with respect to the degrees of relative effects stemmed from the pair comparisons in Eq. (1). An $n \times n$ direct-influence matrix A is obtained based on the directly observed relations, where a_{ij} indicates the degree of impacts of the i factor on the j factor (Taghizadeh Herat et al. 2012).

$$A = \begin{bmatrix} a_{11} & a_{1j} & a_{1n} \\ a_{i1} & a_{ij} & a_{in} \\ a_{n1} & a_{nj} & a_{nn} \end{bmatrix}$$

1

Step 3

The normalized matrix obtains from Eqs. (2) and (3)

$$X = s. A$$

2

$$s = \min \left[\frac{1}{\max \sum_{j=1}^n |a_{ij}|}, \frac{1}{\max \sum_{i=1}^n |a_{ij}|} \right]$$

3

where the all matrix diagonals equals to zero and the sum of each column and raw does not exceed 1.

Step 4

Deriving the full relationship matrix T from the Eq. (4)

$$T = X + X^2 + \dots + X^k = T = X(1 - X)^{-1}$$

4

Step 5

Summing each column and row to obtain D and R Eqs. (5) and (6)

$$D = \left(\sum_{j=1}^n T_{ij} \right) = [d_i]_{nx1}$$

5

$$R = \left(\sum_{i=1}^n T_{ij} \right) = [r_j]_{1xn}$$

6

Here, d_i shows the sum of each row in T and the rows indicates the degrees of direct and indirect effects over the other criteria, and r_j is considered as the sum of each column in T, where columns refers to the effect degree from other criteria. Thus, numeric algorithm variable d_i , indicates the factors affecting others, r_j shows those which are affected by others, $d_i + r_j$ is considered as the relationship degree between factors, $d_i - r_j$ is the effect degree among factors (Lee et al. 2011).

Step 6

Evaluating a threshold value for disregarding the minor effects is essential for separating the relationship structure of the factors and obtaining NRM (Yang and Tzeng 2011).

2.4.2. ANP method

ANP method

Step 1: In this step, a conceptual model is designed and the relationships between/among clusters and nodes are evaluated.

Step 2: Super Decisions software is used for comparing the criteria in the whole network for the purpose of creating an unweighted supermatrix based on pairwise comparisons. In this stage, two elements are compared by decision makers. Pairwise comparisons are established based the marks ranging from 1 to 9 (Vasiljević et al., 2012). A reciprocal value of each number is applied for indicating the inverse comparison. The values of pairwise comparisons are specified in the comparison matrix and local priority vector is stemmed from eigenvector. Like the AHP, the consistency of pairwise matrix should be less than 0.1 (Sener et al., 2011).

Step 3

The weights created from the previous steps are introduced into the supermatrix including the entire network components, which shows their inter relationships. In this step, supermatrix is called the initial supermatrix. Eq. (7) indicates the general form of the supermatrix.

$$W = \begin{matrix} & \begin{matrix} C_1 & C_2 & \dots & C_n \\ e_{11} \dots e_{1m_1} & e_{21} \dots e_{2m_2} & \dots & e_{n1} \dots e_{nm_n} \end{matrix} \\ \begin{matrix} C_1 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} W_{11} & W_{12} & \dots & W_{1n} \\ W_{12} & W_{22} & \dots & W_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ W_{n1} & W_{n2} & \dots & W_{nn} \end{bmatrix} \end{matrix} \quad (7)$$

C_k is considered as the k th cluster ($k = 1, 2, \dots, N$) which includes n_k elements refers to $e_{k1}, e_{k2}, \dots, e_{kn}$. A matrix segment, W_{ij} , shows a relationship between the i th and j th clusters. Each column of W_{ij} is a local priority vector made from the corresponding pairwise comparison, which indicates the significance of the elements in the i th cluster on an element in the j th cluster (Lee et al. 2009).

Step 4

The cluster weights should be calculated for weighing the initial supermatrix. The initial supermatrix can be measured by multiplying the cluster weights matrix by an initial supermatrix after obtaining the cluster weight matrix (Nekhay et al., 2009). The new obtained matrix is known as the weighted supermatrix.

Step 5

Finally, the weighted supermatrix n times are multiplied by itself until reaching the limit supermatrix. Some super matrices may play a cyclicity effect, which results in obtaining two or more final limit super

matrixes. Having equal columns and representing the global priority vectors are considered as the main properties of the limit supermatrix (Nekhay et al. 2009).

3. Result And Discussion

Efficient factors for assessing urban resilience were determined based on the literature review and area conditions. A part of the criteria layer is presented in Fig. 4. The DEMATEL based ANP method was used since that multiple criteria had different effects on the process of assessing urban resilience. Considering the fact that the ANP model investigates the relative importance of criteria in the network, it was essential to apply the DEMATEL approach to resolve the issues of interactions or interdependence among the criteria. Thus, the current study has three results that involved: building the Network Relation Map (NRM), determining the weights of criteria, and generating Urban Resilience Map (URM).

3.1. Building the Network Relation Map (NRM)

The first result was the dependent relationships between the criteria. Tables 5 and 6 show the amount of the interaction between the criteria and dimensions. Figure 5 shows INRM for a visual representation of the four dimensions and their criteria.

Table 5
Sum of influences given and received on dimensions

Dimension	d_i	r_i	d_i+r_i	d_i-r_i
A	5.96	4.77	10.73	1.18
B	4.97	5.55	10.52	-0.58
C	6.02	5.40	11.42	0.62
D	5	6.22	11.22	-1.22

Table 6
Sum of influences given and received on
criteria

Criteria	d_i	r_i	d_i+r_i	d_i-r_i
A1	2.46	1.35	3.81	1.11
A2	1.35	1.79	3.14	-0.44
A3	1.97	1.58	3.56	0.39
A4	1.06	2.13	3.19	-1.06
B1	3.13	1.94	5.07	1.19
B2	2.71	2.33	5.04	0.38
B3	1.43	3	4.43	-1.57
C1	4.47	3.35	7.82	1.13
C2	3.92	3.45	7.37	0.48
C3	3.29	3.63	6.92	-0.34
C4	3.20	4.46	7.67	-1.26

The value of $(d_i - r_j)$ listed the criteria in cause-and-effect classes. As can be seen in Table 5 and Fig. 5, the environmental dimension (D1) has the highest $(d_i - r_j)$ value with 1.18, which has a direct impact on other dimensions. In addition, the influential impact degree of (D1) is 5.95 (Table 5), which is ranked as the second-highest degree among all causal dimensions. 'Socio-economic (C)' dimension has a significant impact on other cause group dimensions with the second highest $(d_i - r_j)$ value of 0.61. Additionally, (C) has the first highest r_i value (6.01) among the causal dimensions in terms of prominent impact degree. Institutional (D) aspect has the lowest value of $(d_i - r_j)$ with (- 1.22), which is the most vulnerable to influence. Generally, A affects C, B, and D dimensions ($A \rightarrow \{C B D\}$), C affects B and D dimensions ($C \rightarrow \{B D\}$), and B affects D dimensions ($B \rightarrow \{D\}$). Understanding these cause-and-effect relationships helps planners and urban managers make decisions for solving resilience issues. For instance, urban planners should first take action to develop the D (Environmental) dimension, and then C (Socio-economic), B (Physical), and D (Institutional) dimensions, respectively. Furthermore, the causal diagram shows that among the four dimensions, the socio-economic (C) dimension has the highest prominence $(d_i + r_j)$ value with 11.42 (Fig. 5). Prominence ranking is listed from the highest to the lowest value as follows: C (Socio-economic), D (Institutional), A (Environmental), and B (Physical).

Figure 5 and Table 6 demonstrate the most significant causal criteria. As can be seen, A1 affects A3, A2, and A4 criteria ($A1 \rightarrow \{A3 A2 A4\}$) in the environmental dimension. According to Table 6, the $(d_i - r_j)$ values of the A1 (Disasters and natural hazards) and A3 (Environmental pollutants) criteria are positive.

Hence, this criterion is classified as the cause group. Disaster and natural hazard criteria (A1) have the maximum positive value ($d_i - r_j$) (1.11), and indicates that it has a significant effect on all of the criteria. Further, the A2 (Water resources) and A4 (Topography) criteria were located in the effect class due to the negative amount of ($d_i - r_j$) values. Topography (A4) has the minimum negative value ($d_i - r_j$) (-1.06) and receives a significant effect from cause class criteria. The results indicate that urban managers in Tehran can improve urban resilience in the environmental dimension by identifying types of natural hazards such as floods, earthquakes, and landslides and preparing vulnerability maps to identify safe situations for citizens in hazard situations.

Further, B1 affects B2 and B3 criteria ($B1 \rightarrow \{B2 B3\}$) in the physical dimension. This finding indicates that the ($d_i - r_j$) values of the B1 (Urban infrastructure) and B2 (Land use) are positive between these criteria and can influence all criteria. Urban infrastructure (B1) has the highest ($d_i - r_j$) value with 1.19, which impacts the other sub-criteria of the physical dimension. In addition, the results show that B3 (Green space) is negative, has the minimum negative value ($d_i - r_j$) (-1.57), and is affected by other criteria. Therefore, urban managers can improve urban resilience in the physical dimension by observing international standards of design and planning for providing the infrastructure and facilities. Additionally, they can protect vital and infrastructural public facilities through reconstruction.

C1 affects C2, C3, and C4 criteria ($C1 \rightarrow \{C2 C3 C4\}$). The employment rate (C1) is another significant criterion since the ($d_i - r_j$) value is the maximum value (1.13) in the socio-economic dimension. Furthermore, the results indicate that C3 (Health status) and C4 (Insurance type) are negative and are influenced by other criteria. C4 has the minimum negative value ($d_i - r_j$) (-1.26). Therefore, urban managers can improve urban resilience by stabilizing the economic activities in the district, providing employment facilities, and taking measures to attract investment to diversify economic activities and increase people's financial capacity. Similar influential relationships could also be defined for the other criteria, as illustrated in details in Fig. 5. Fontela and Gabus (1976) stated that due to internal relationships between factors, more attention should be paid to the cause class criteria due to their impact on the effect class criteria. This method is a useful tool for urban decision-makers to identify priorities for increasing urban resilience. Urban decision-makers can define regular prevention programs based on causal factors to increase urban resilience. Table 7 presents a preventive program for the most important causal factors in urban resilience according to Tehran situation.

Table 7
The preventive program for the most important causal criteria in urban resilience

Code	Causal Criteria	Preventive Program
A1 A3	Disasters and natural hazards Environmental pollutants	<ul style="list-style-type: none"> • Identifying types of natural hazards in Tehran • Preparing vulnerability maps to identify safe locations for citizens in hazard situations. • Repair infrastructure vulnerabilities in the shortest possible time after the crisis. • Granting incentives and financial facilities and tax exemptions for factory owners to purchase and use machines and machines with high standards and less pollution.
B1 B2	Urban infrastructure Land use	<ul style="list-style-type: none"> • Updating the facilities of fire centers. • Updating the facilities of medical centers. • Build and upgrade the facilities of crisis management support bases in districts and neighborhoods with a suitable access radius. • Creating multi-purpose land uses with emphasis on green space and open space for temporary housing in times of crisis. • Paying attention to the compatibility of land uses and their impact on the crisis.
C1 C2	Employment rate Population and education	<ul style="list-style-type: none"> • Promoting economic activities in the district for economic recovery after the crisis. • Increase business and investment opportunities to increase urban economic resilience. • Implementing regulations that limit building density to increase resilience. • Implementing regulations that limit population density to increase resilience. • Educating citizens to prepare for a crisis through photos, posters, seminars, etc. • Implement programs for citizens to identify hazards, increase awareness of hazards, safety training, etc.

3.2. Determining the weights of criteria

The second result is related to determining the weights of the criteria. Based on the performance matrices of DEMATEL method, ANP was used to measure the criteria weight in a network structure. Finally, the limits of the super-matrix W^{α} were applied to obtain the criteria weights presented in Table 8 and Fig. 6.

Table 8
Influence weights of urban resilience assessment

Dimension	Global Weight	Ranking	Criteria	Global Weight	Ranking	Sub-criteria	Global Weight	Ranking			
A	0.27	1	A1	0.120	2	A1-1	0.077	1			
						A1-2	0.061	2			
			A2	0.073	9	A2-1	0.044	7			
						A2-2	0.027	17			
			A3	0.099	5	A3-1	0.028	16			
						A3-2	0.031	14			
						A3-3	0.031	14			
			A4	0.0583	11	A4-1	0.003	27			
						A4-2	0.004	26			
			B	0.24	3	B1	0.126	1	B1-1	0.020	23
B1-2	0.028	16									
B1-3	0.021	22									
B1-4	0.020	23									
B1-5	0.041	8									
B2	0.109	3				B2-1	0.014	24			
						B2-2	0.011	25			
						B2-3	0.010	26			
						B2-4	0.058	3			
						B2-5	0.025	18			
B3	0.062	10				B3-1	0.034	12			
						B3-2	0.028	16			
C	0.26	2				C1	0.105	4	C1-1	0.054	4
									C1-2	0.050	5
			C2	0.093	6	C2-1	0.047	6			
						C2-2	0.037	10			
						C2-3	0.040	9			

Dimension	Global Weight	Ranking	Criteria	Global Weight	Ranking	Sub-criteria	Global Weight	Ranking
			C3	0.078	7	C3-1	0.024	19
						C3-2	0.023	20
						C3-3	0.030	15
			C4	0.077	8	C4-1	0.032	13
D	0.23	4				D1-1	0.022	21
						D1-2	0.036	11

As shown in Table 8, the environmental dimension with a weight of 0.27 has a more important effect on urban resilience in comparison to other dimensions. It is noteworthy that the weights of the percentage of critical infrastructure vulnerabilities in the event of a natural disaster (0.077), the degree of the vulnerability of the infrastructure to hazards (0.061), the worn-out texture rate (0.058), the employment rate (0.054), the poverty line (0.05), and the population density (0.047) are the most important sub-criteria in comparison to other sub-criteria. Therefore, these six sub-criteria are the key factors for assessing urban resilience.

3.3. Urban Resilience Map (URM)

In the third result in related to applying the Weighted Overlay method for generating the urban resilience map. In this approach, the criteria weights obtained by the DANP model was multiplied into the criteria layer, and the layers were integrated. The urban resilience map was calculated based on the following equation:

$$URM = [(A1-1 \times 0.077) + (A1-2 \times 0.061) + [(A2-1 \times 0.044) + (A2-2 \times 0.027) + (A3-1 \times 0.028) + (A3-2 \times 0.031) + (A3-3 \times 0.031) + (A4-1 \times 0.003) + (A4-2 \times 0.004) + (B1-1 \times 0.02) + (B1-2 \times 0.028) + (B1-3 \times 0.021) + (B1-4 \times 0.02) + (B1-5 \times 0.041) + (B2-1 \times 0.014) + (B2-2 \times 0.011) + (B2-3 \times 0.01) + (B2-4 \times 0.058) + (B2-5 \times 0.025) + (B3-1 \times 0.034) + (B3-2 \times 0.028) + (C1-1 \times 0.054) + (C1-2 \times 0.05) + (C2-1 \times 0.047) + (C2-2 \times 0.037) + (C2-3 \times 0.04) + (C3-1 \times 0.024) + (C3-2 \times 0.023) + (C3-3 \times 0.03) + (C4-1 \times 0.032) + (D1-1 \times 0.022) + (D1-2 \times 0.036)] (8)$$

Then, the urban resilience map was classified into five categories for visual interpretation. Figure 7 displays the final resilience map.

Figure 7 shows the spatial pattern of Tehran metropolis resilience as well as the districts which need additional attention. The spatial patterns of resilience rates show that districts with very high to high resilience (Districts 4, 1, 2, 5, and 22) are located in the northwest to northeast parts of the study area (Table 9).

Table 9

Area and percentage of resilience degree in 22 districts of Tehran

Classes	District	Area	
		ha	Percent
Very low	10, 12	2162	3.5
Low	9, 17, 14, 11, 7, 8	8286	13.5
Moderate	3, 6, 13, 15, 16, 20, 19, 18, 21	23118	37.7
High	1, 2, 5, 22	20450	33.5
Very high	10, 12	7243	11.8

The household economy situation in these districts is moderate to high. These districts include mostly old residents and immigrants with high economic and social status. Furthermore, access to welfare facilities, urban infrastructure, social services, and large green spaces such as Chitgar, Koohsar, and Kan forest parks for local communities is better than other districts. The districts with moderate resilience (Districts 3, 6, 21, 18, 19, 16, 15, 20, and 13) are mostly located in the southern, southwestern, and western areas of the study area. According to Fig. 8, 17% of the total area of Tehran is located in 'very low' and 'low' resilience classes. Districts with very low to low resilience (Districts 7, 8, 9, 10, 11, 12, 14, and 17) are in the central and eastern areas of the study area. These districts have a very low to low degree of resilience due to high population density, worn-out texture, the vulnerability of infrastructure to hazards, air pollution because of compact urban structure, and many commercial land uses. This study aimed to provide opportunities for urban planners and decision-makers to reflect their decisions based on the DANP method. The advantages of DEMATEL based ANP technique for decision-makers could be stated as follows:

- It is a proper method of MCDM which is used to identify the pattern of causal relationships between the variables.
- This method has clarity and transparency for showing the interrelationships between an extended range of criteria as compared to the network analysis approaches, which can help experts express their views on the direction and intensity of the effects among factors with more knowledge.
- It expresses the direction and intensity of the effects between the criteria in a quantitative way by presenting diagrams for visual interpretation.
- It determines the importance and weight of the factors by considering all available factors and dimensions.
- Structuring complex factors in the form of cause-and-effect groups is one of the most important functions, which could be considered as one of the most important reasons for its widespread use in problem-solving processes. By dividing a wide range of complex factors into cause-and-effect

groups, it puts the decision-maker in a better position to understand relationships, which can result in a greater understanding of the position of factors and their role in the interaction process.

- The ANP technique used in this study is a suitable tool for network ranking and does not require a hierarchical structure. Thus, it shows the more complex relationships between different levels of a decision in a network. In fact, it considers the interactions and feedback between the criteria and provides a suitable framework for analyzing the problem.

4. Conclusion

Today, there are many changes in attitudes toward hazards, and the views of the world community have shifted from focusing on reducing vulnerability to increasing resilience in response to hazards. Accordingly, urban decision-makers focus on hazard reduction programs by developing and strengthening the characteristics of resilient cities and communities which are in line with sustainable development goals. The present study aimed to assess urban resilience in order to use management and prevention programs before the occurrence of natural and human hazards by using the combined Delphi and ANP-DEMATEL method for identifying and evaluating important urban resilience criteria, determining the internal relationships between the criteria, and assessing their impacts on each other.

This study aimed to determine at least a set of appropriate and clear criteria based on experts' opinions by the Delphi method. This method decreases the decision time for urban planners. Considering the Delphi findings, four dimensions, 11 criteria, and 32 sub-criteria were employed for assessing urban resilience. As Kharat et al. (2016) and Shi et al. (2020) maintain, the Delphi method is an effective method for measuring criteria and finding optimal solutions which can effectively convert vague, subjective, and linguistic data from experts' opinions into quantitative and logical results. In the present study, the DEMATEL combination with ANP approaches was used to determine the interdependent relationships among the criteria and their importance. Azizi et al. (2014) stated that ANP cannot assign the strengths and internal relationships between the criteria and does not pay attention to this issue, which could cause the model results to deviate from the real situation. To overcome this shortcoming, DEMATEL was applied along with ANP. Wang et al. (2018) stated that the DEMATEL based ANP method can correct the deficiency of the ANP method and reflect the interdependent feedback relationships between the factors, which could ensure that the results are scientific and reasonable. Based on the DEMATEL method, A1 (Disasters and natural hazards) in the environmental dimension, B1 (Urban infrastructure) in the physical dimension, and C1 (Employment rate) in the socio-economic dimension had the highest degree of effect ($d_i - r_j$). The results of this study revealed that DEMATEL based ANP is a good approach for better understanding the issues and can help urban planners make accurate decisions. The findings help urban planners consider the criteria of the cause group for defining priority prevention programs to increase urban resilience. In this study, different criteria in several dimensions were used to show the degree of resilience against unpredictable stresses and shocks. However, the unavailability and inaccessibility of data for some criteria were the limitations of the study. Consequently, some of the criteria should be omitted since they might influence the obtained results. For instance, the

institutional dimension, which plays a significant role in the preparedness and planning stage for hazard resilience was measured by only two criteria to this limitation. Finally, it is suggested that further research be conducted on the resilience of the influencing factors in each of the dimensions introduced by the DANP method.

5. Declarations

Data availability The datasets generated and/or analyzed during the present study are available upon reasonable requests from the corresponding author.

Declaration of Interests There is no competing interests amongst the authors.

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Figures

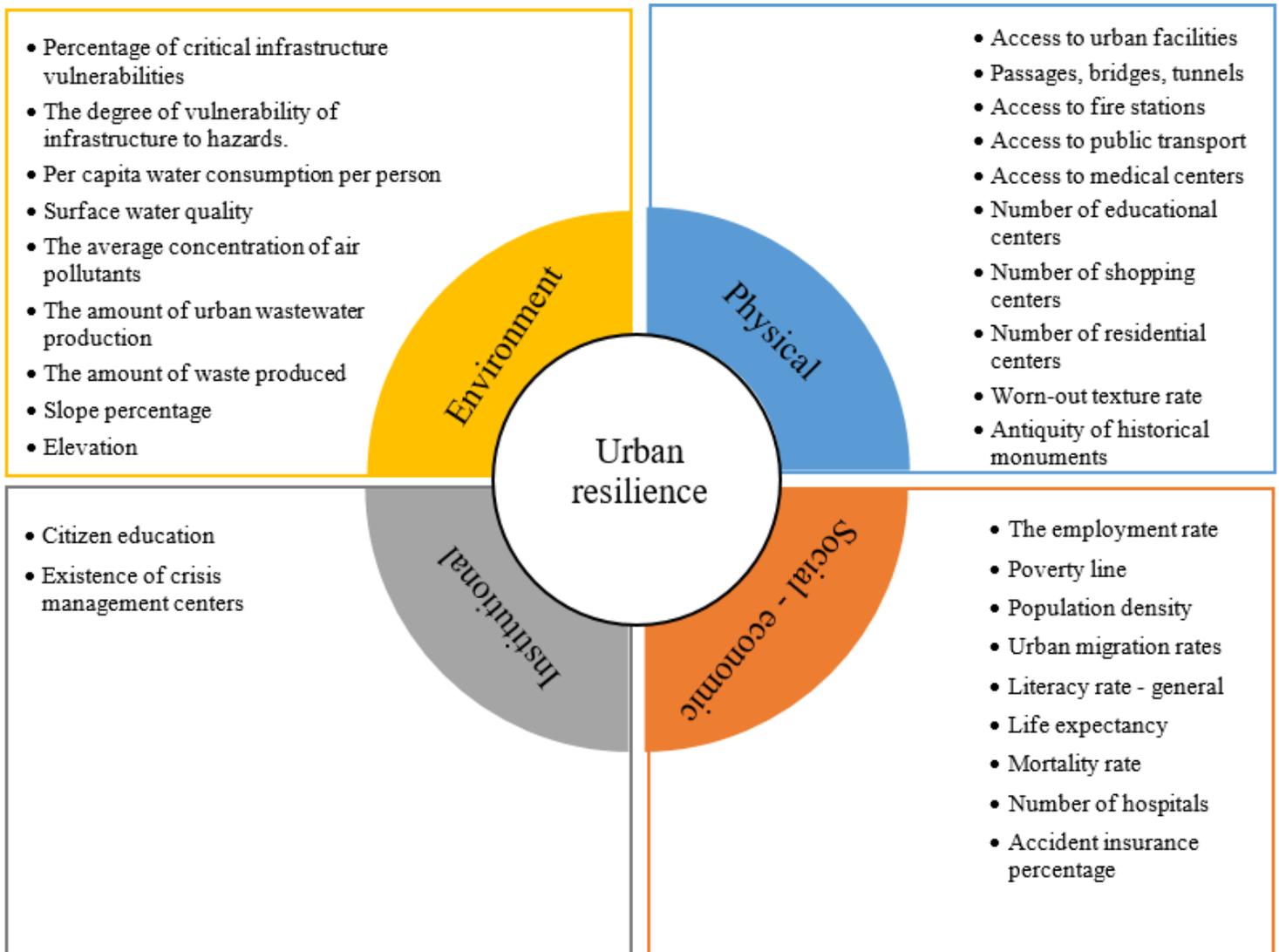


Figure 1

The sub-criteria effective in urban resilience assessment

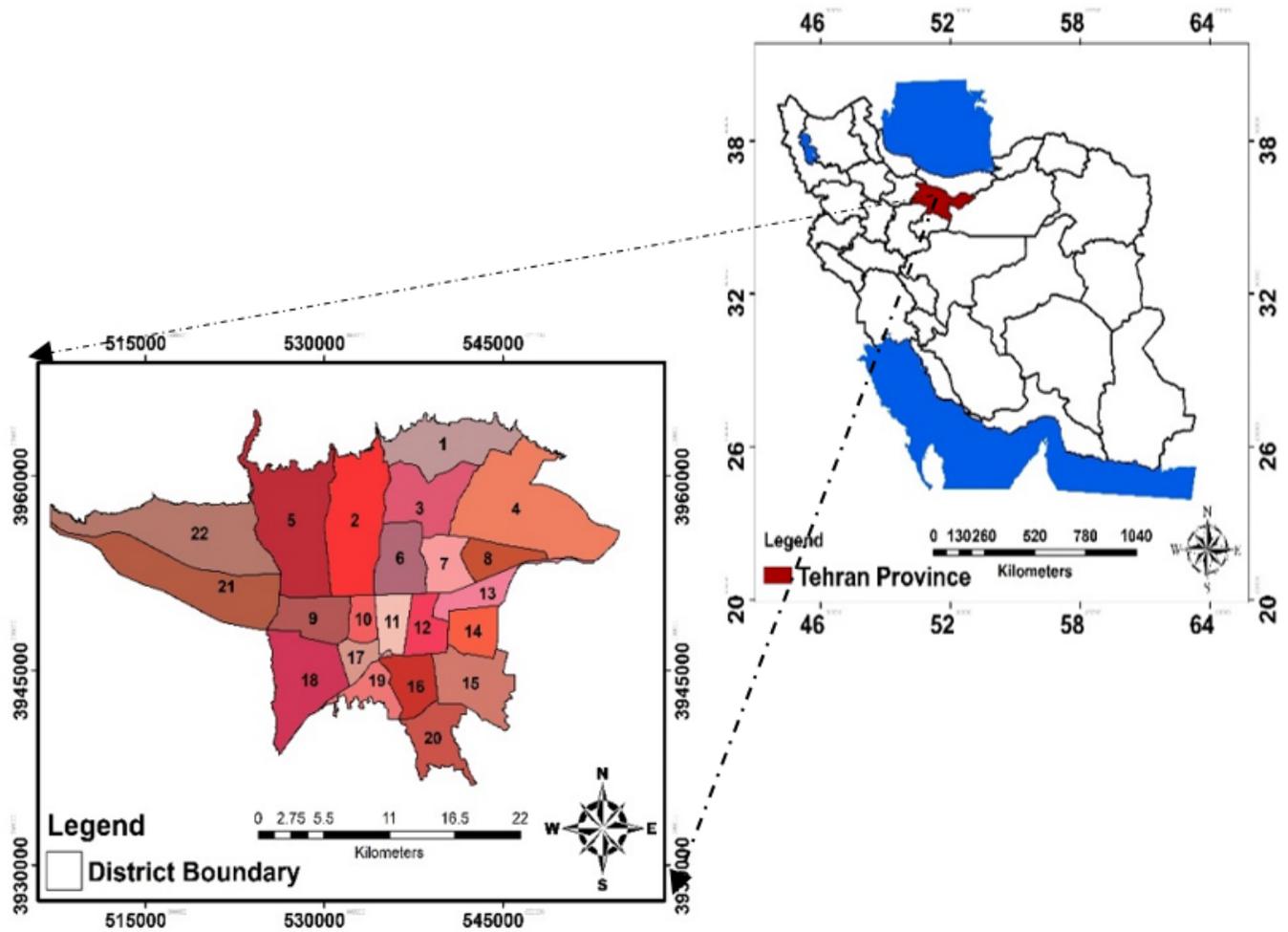


Figure 2

Location map of the study area

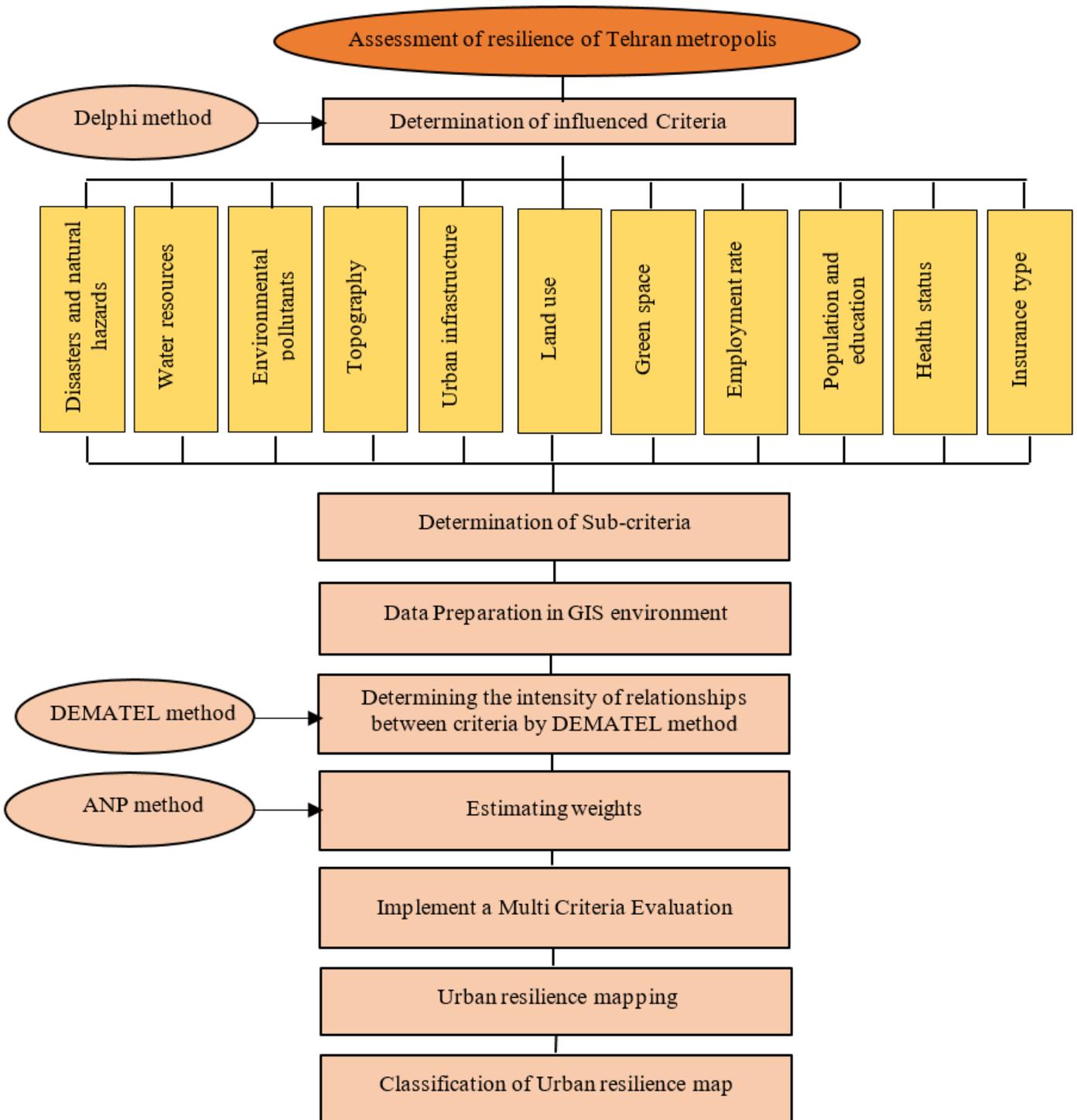


Figure 3

Schematic flowchart of the methodology

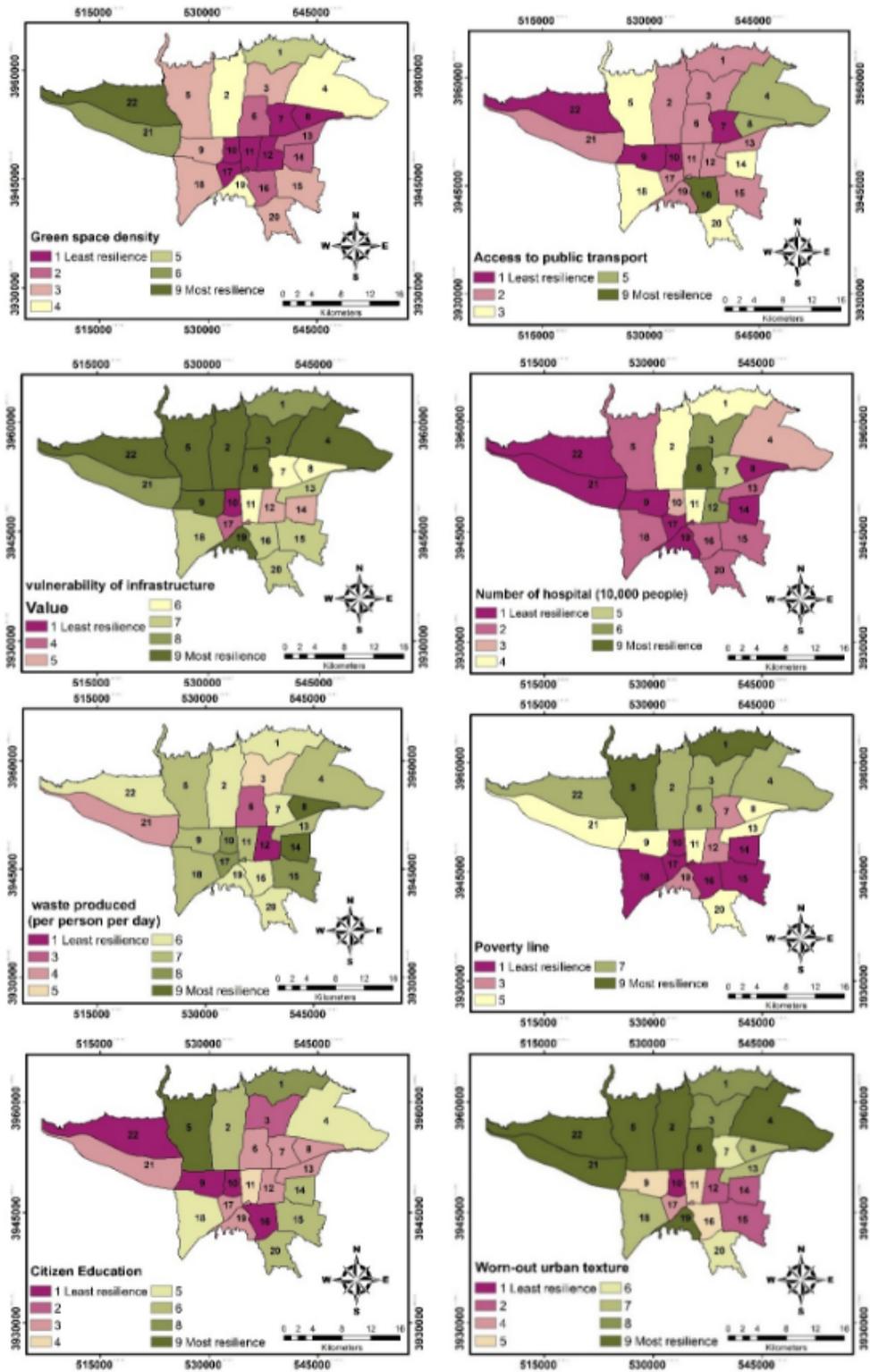


Figure 4

Part of the criteria layer are used in urban resilience assessment

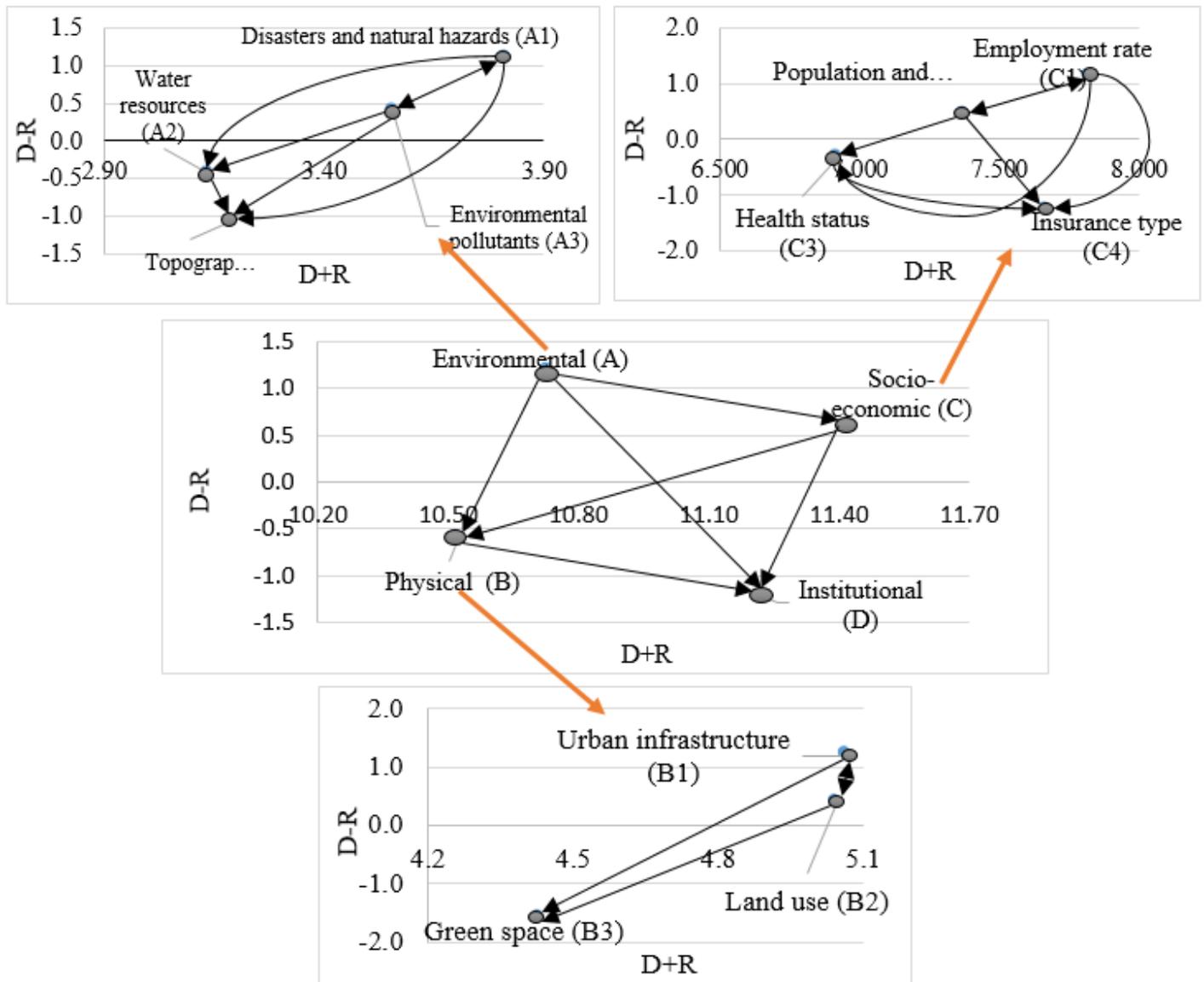


Figure 5

Influential network relation map (INRM) of urban resilience assessment

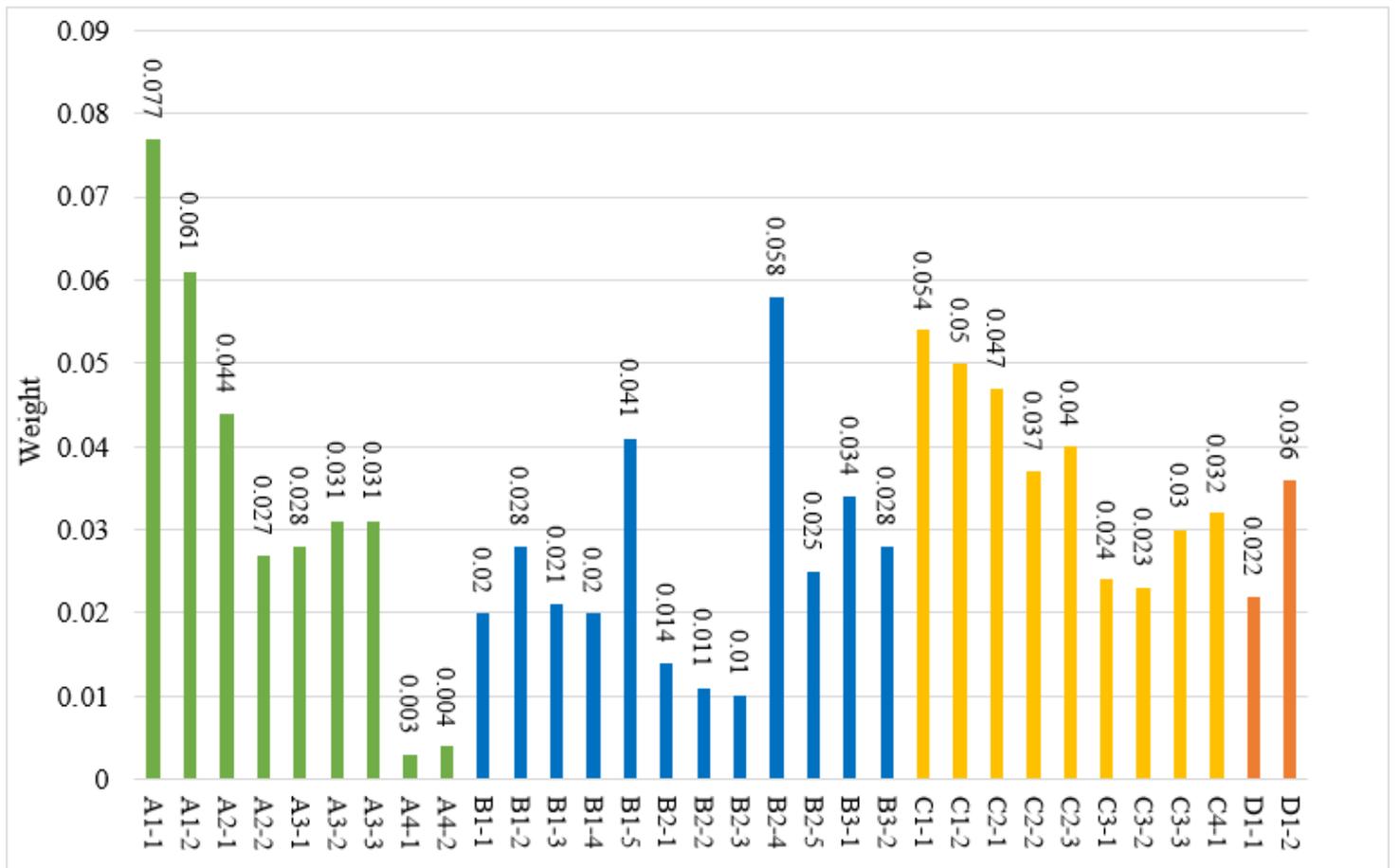


Figure 6

Effective weight of sub-criteria in urban resilience assessment

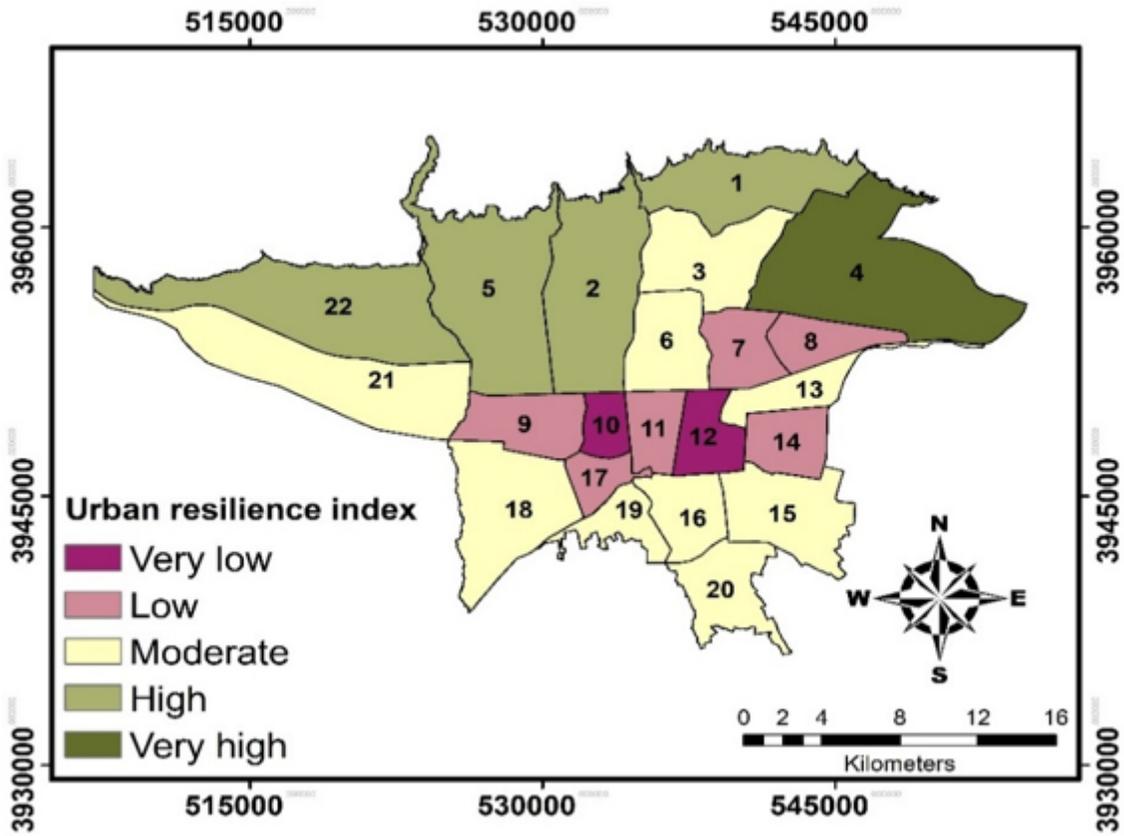


Figure 7

Urban resilience index for 22 District of Tehran

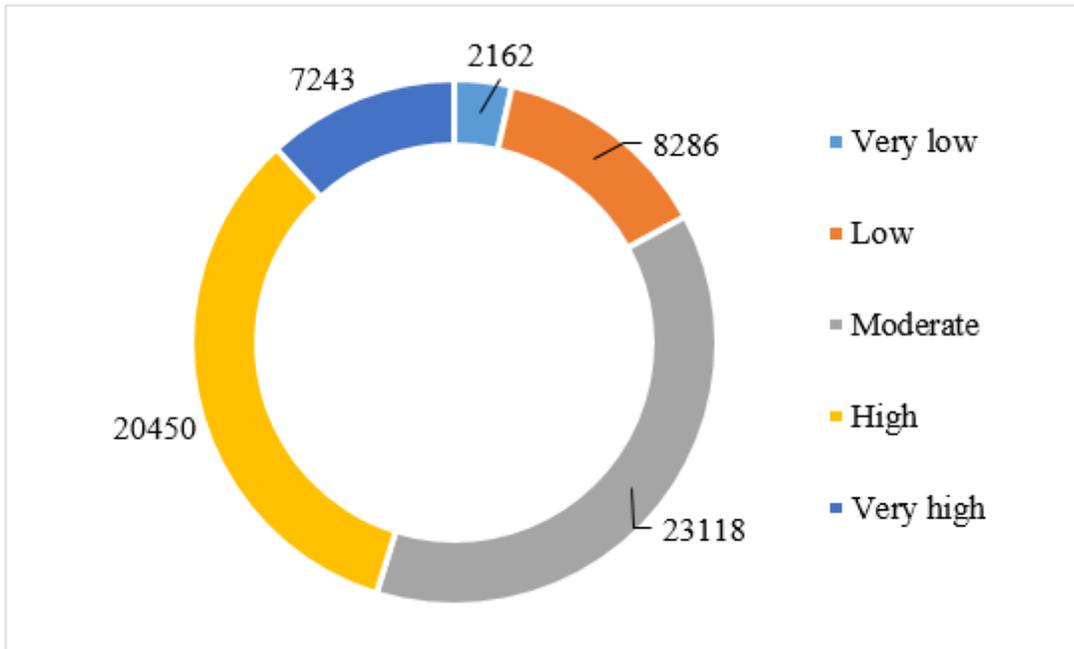


Figure 8

Area of resilience degree in 22 districts of Tehran (ha)