Analyzing the resilience of urban settlements using multiple-criteria decision-making (MCDM) models (case study: Malayer city)

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ABSTRACT
The aim of this study is to assess environmental resilience through the analysis of quantitative and qualitative indices on urban settlements in Malayer city, Iran. We used a decision-making matrix, standardization of indicators based on fuzzy method, ideal indicators, matrix coefficient change based on the weight of indices, the ideal positive and negative solutions, distance measure, and the relative proximity of the ideal solution using multi-criteria decision-making (MCDM). Also, to analyze environmental resilience indexes, we used GIS and TOPSIS software. The results show that the resilience rate in Malayer city shows essential diversity in resilience. Results of the resilience rate show the critical difference from 2.17% in deficient resilience class, 6.14% in low resilience class, 25.67% proper resilience, and 66.02% high resilience. The present study, as a regional pattern, showed the resilience rate in urban settlements using the multi-criteria decision-making method (MCDM).

1. Introduction
Environmental resilience is an essential aspect of urban planning because it is the most important factor of site-selection and urban settlements. Currently, the planners studied various physical and human factors variability in environmental resilience in Asia, including Iran. Also, physical and human factors variability affects the spatiotemporal designs of site-selection and urban settlements. In the environmental resilience study, Harrison (1979) showed that stability showed an increased diversity of resources in the environmental resilience in increased resistance to changes (Harrison, 1979). Some researchers have studied the effects of environmental resilience on urban issues (Lu, 2020; Miller & MacIntosh, 1999; Okvat & Zautra, 2011; Zuniga-Teran, 2020). Analysis of environmental resilience is an influential aspect in studying the influence of physical and human factors variability on the site-selection change and urban planning (Javari, 2016; Panagopoulos et al., 2016). Thus, the assessment of physical and human factors on environmental resilience is necessary (Van Hoof, 2018). Physical and human factors could affect urbanization changes by considering environmental resilience (Li, 2013; Sun, 2016). In this study, we analyzed the environmental resilience in Malayer city to estimate any essential variations in the natural, accessibility, privacy, and social factors on urban settlements. We can group the environmental resilience factors based on physical and human factors (Parker & Simpson, 2020; Therrien et al., 2020). Based on physical factors, use can reduce the granularity of urban parts, the number of floors, age of buildings, building density, building quality, building material quality, climate change, geological structure, ecological factors, water sources, etc., by considering city separately (Admiraal & Cornaro, 2020; Himeur, 2020). In human factors, consider the social, political, economic, accessibility (access to streets, access to green spaces, access to fire stations, access to health centers, access to educational centres, access to open spaces, access to shelters) factors by considering each city independently (Jiménez Ariza, 2019; Ribeiro & Pena Jardim, 2019; Syrbe & Chang, 2018). The change of urbanization has an important influence on population distribution. However, the effectiveness of population distribution considers the effective factor in environmental resilience (Chen, 2020; Ives, 1995), which has a little study in Iran. We considered the urban population density to the environmental resilience based on spatiotemporal changes between the urban population density and its...
urban population distribution (Fan et al., 2020). Population density changes and urban population based on distribution and size affect environmental resilience in various cities for different periods (De Souza, 2015; Xu et al., 2020). Also, the physical aspects in a spatial realm (Javari, 2017) can consider as an expected environmental resilience (Cutter et al., 2014). However, we used physical aspects such as the number of floors and the age of buildings (Colding & Barthel, 2013) in environmental resilience for regional planning. Accessibility is another aspect in the study of environmental resilience (Reggiani, 2013). The change of accessibility based on the access to streets, access to green spaces, access to fire stations, access to health centres, access to educational centres, access to open spaces, and access to shelters and temporary accommodation centres, etc., has an important influence on the environmental resilience (Brown, 2013; Reggiani, 2013). However, we have employed various physical factors to study environmental resilience (Mandakovic, 2018; Xiong et al., 2020). In this study, to assess environmental resilience, we used the earth slope, distance from faults, distance from flood-prone areas, and land area. Fuchs et al. (2012) present a natural hazard and risk analysis (Fuchs et al., 2012). Results to manage natural hazards, risk present the concept of vulnerability compared with an environmental resilience rate. Various reports have used social factors such as population density to test environmental resilience in recent years. In environmental resilience analyses, researchers used the multi-criteria, PCA, AHP, etc. methods (Davoudabadi et al., 2020; Vega et al., 2016) based on the spatiotemporal distribution to estimate the resilience of urban settlements. However, we used multi-criteria and AHP methods to estimate the environmental resilience of urban settlements. In the reports, vulnerability types used the applied multi-criteria, PCA, AHP, etc., methods. The analysis methods of urban settlement’s resilience show various elements such as passages, open spaces, the shape of buildings, and congestion patterns in different regions (Alberti & Marzluff, 2004; Farhan & Lim, 2011; Nop & Thornton, 2019). In this study, we used the multi-criteria decision-making method (MCDM) based on the decision-making matrix, standardization of indicators based on fuzzy method, ideal indicators, matrix coefficient change based on the weight of indices, the ideal positive and negative solutions, distance measure, and the relative proximity of the ideal solution. MCDM is a common method to analyze urban settlement’s resilience. In this study, the MCDM method based on the discrete Multi-Attribute Decision-Making (DMADM) and continuous Multi-Objective Decision-Making (CMODM) (Mojtabedi & Oo, 2016) used the multi-optimal probable options to analyze the urban settlement’s resilience in Malayer city. The MCDM method in the DMADM and the CMODM models are important techniques in simulating and estimating the urban settlement’s resilience. The relationship between the spatiotemporal effects of the urban settlement’s resilience has studied the distribution of the indicators using ArcGIS10.8 software and by selecting the indicators using the TOPSIS Multiple-Criteria Model (TMCM).

The major aim of this study is to analyze an urban settlement’s resilience in Malayer city using the MCDM method. To assess the urban settlement’s resilience, we use the physical (the granularity of urban parts, number of floors, age of buildings, building density, building quality, and building material quality) factors, the accessibility (access to streets, access to green spaces, access to fire stations, access to health centres, access to educational centres, access to open spaces, and access to shelters and temporary accommodation centres), the distance from gas stations, natural factors (earth slope, distance from faults, and distance from flood-prone areas), and social (population density) factors. We also processed the resilience of urban settlements under different environmental conditions using GIS-based patterns. We can use the findings of this research in environmental and urban planning in Iran.

2. Materials and methods
2.1. Study area and data

Malayer, located southeast of Hamadan Province, is at 34.29° N latitude and 48.825° E longitudes in the west of Iran. In the 2016 census, the population in Malayer was 290,137, in 89,762 families with an area is almost 3410 km² (Figure 1). It has two geographical regions with a specific topographical condition to the mountainous and plane patterns. Malayer has a Mediterranean climate, mostly influenced by the winter precipitation and dry summer. The precipitation distribution results based on atmospheric circulation systems in two rainy and dry seasons in the different parts of the Malayer. Annual average precipitation and temperature are about 358.7 mm and 8.5°C, respectively. In this study, the resilience of urban settlements of Malayer focuses on physical (the granularity of urban parts, number of floors, age of buildings, building density, building quality, and building material quality), accessibility (access to streets, access to green spaces, access to fire stations, access to health centres, access to educational centres, access to open spaces, and access to shelters and temporary accommodation centres), area (the distance from
gas stations), natural factors (earth slope, distance from faults, and distance from flood-prone areas), social (population density) factors.

2.2. Methods

This paper supposes a method to assess the resilience rate on urban settlements, using the valuation of each criterion, weighing the criteria, the weighting of each criterion using the AHP method and Expert Choice, layers made using the ArcGIS environment, and overlapping the layers of resilience using the TOPSIS. It also analyzes four different levels of urban resilience in Malayer based on the 18 indicators (Table 1). Figure 2 shows the schematic chart of the modelling of the resilience degree in Malayer City. First, we use the evolution of 18 indicators in Malayer using TOPSIS Technique: the best option, the shortest distance with the ideal solution (the best possibility), and the maximum distance with the ideal negative solution (the worst possibility). We use an effective method for prioritization to analyze the multi-indexing models of resilience rate on urban settlements, evaluate them options by n indicators, and compare the ideal positive solution with the maximizes the benefits of indicators and minimizes their cost to an ideal negative solution scale resilience with the minimizes the cost of the indicators and minimizes their benefits. We use the ideal positive solution to combine the best values to oppose the ideal negative and determine the worst accessible values of indicators. We use the TOPSIS technique to classify the weighting of the indicators based on responses of significant conformity. Also, we consider the TOPSIS technique to assess urban resilience based on the simplicity and speed of the technique, consideration of the negative and positive effects of the indicators, acceptability of the initial weight coefficients, specifying the order of priority of the options quantitatively through their outputs, and matching the results of the model with empirical methods. Finally, we use the aim and subjective criteria and indicators simultaneously to access the resilience rate on urban settlements using the TOPSIS

Table 1. The research indicators

| Indicator                  | Physical                          | Accessibility                       | Area                                      | Social                                      | Natural                       |
|----------------------------|-----------------------------------|-------------------------------------|-------------------------------------------|---------------------------------------------|-------------------------------|
| Criteria                   | The granularity of urban parts    | Access to streets                   | The distance from gas stations            | Population density                         | Earth slope                   |
|                            | Number of floors                  | Access to green spaces              |                                           |                                             | Distance from faults          |
|                            | Age of buildings                  | Access to fire stations             |                                           |                                             | Distance from flood-prone areas |
|                            | Building density                  | Access to health centres            |                                           |                                             |                               |
|                            | Building quality                  | Access to educational centres       |                                           |                                             |                               |
|                            | Building material quality         | Access to open spaces               |                                           |                                             |                               |
|                            |                                   | Access to shelters and temporary    |                                           |                                             |                               |
|                            |                                   | accommodation centres               |                                           |                                             |                               |
method. In this study, we used the TOPSIS model to test the resilience rate of urban settlements in Malayer. The TOPSIS model includes the following steps:

First, we compute the creation of a spatial matrix based on m options and n properties in Malayer using a set of X and Y points that contain the geographical substrate. Second, we estimate the normalized value to check the different units to measure the urban settlements’ resilience rate. We use a method of standard between 18 indicators of resilience rate in urban settlements. We present the standard resilience rate on urban settlements as follows (Moghadas, 2019):

\[
n_{ij} = \frac{a_{ij} - a_{\text{mini}}}{\max(a_{ij}) - a_{\text{mini}}} \tag{1}
\]

If the indicator has negative aspects, the following equation is used:

\[
n_{ij} = \frac{\max(a_{ij}) - a_{ij}}{\max(a_{ij}) - a_{\text{mini}}} \tag{2}
\]

where, \(a_{ij}\) use for layers, and \(a_{\text{mini}}\) and \(\max(a_{ij})\) are the minimum and maximum values in the layers, respectively.

Third, we use unscaled matrix coefficients in the weights of indicators to estimate the standardized value (VII). The standardized value (VII) is presented as follows (Orencio & Fujii, 2013):

\[
(V_{ij} = W_{ij} R_{ij}) \tag{3}
\]

where \(W_{ij}\) denotes the weight \(j\) of the index. Thus, \(\sum_{j=1}^{n} w - 1\) it indicates the weight of each of the indicators. In this regard, the indicators of higher importance are also more critical.

We use 18 indicators of resilience rate in urban settlements based on swelling, linear regression, fuzzy normality, distance-based normality, and proportional normality. In this study, we used the standardization of the fuzzy method to measure an element’s membership to define a collection with a value in range one (full membership) to zero (no full membership).

Forth, we determine ideal negative and positive solutions with the following formula (Paatero & Tapper, 1994):

\[
V^+ = \left\{ V_1^+, \ldots, V_n^+ \right\} = \left\{ \max V_{ij} | j \in J \right\}, \left( \min V_{ij} | j \in J \right) \right\} \tag{4}
\]

\[
V^- = \left\{ V_1^-, \ldots, V_n^- \right\} = \left\{ \min V_{ij} | j \in J \right\}, \left( \max V_{ij} | j \in J \right) \right\} \tag{5}
\]

where \(J\) is associated with positive criteria and \(J^-\) and negative criteria. In this positive and negative ideal step, based on the weighted layers are computed.

Fifth, we determine the interval criterion for the ideal alternative \((S_i^+\)) and the minimum alternative \((-S_i^-\)) using Euclidean intervals to measure the urban settlements’ resilience rate. The discrete \(D_j^+\) measurement of each alternative is obtained via PIS using the following formula (Ashtiani, 2009):

\[
D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{ij}^+)^2}, i = 1, \ldots, m \tag{6}
\]

We use a separate measurement of \(D_j\) for each alternative to analyze each alternative is presented as follows (Tzeng et al., 2005):
3. Results and discussion

We used the spatial analysis of building indexes to assess the effective resilience rate’s influential factors on urban settlements in Malayer (Figure 3). The results reveal that the building indexes based on urban parts’ granularity parts were highly different in the spatial distribution. The spatial matrix of the number of floors shows a different distribution of floors from no-floor buildings to four floors and more, that spatial pattern shows different distributions (Figure 3(a)). Also, the plots of the distribution of floors showed that there was an extensive change in the distribution of floors. Therefore, we classify the resilience rate on urban settlements into four levels (low-level resilience, moderate low-level resilience, moderate high-level resilience, and high-level resilience) based on assessing the resilience of spatiotemporal patterns of a matrix of several floors in Malayer (Figure 3(a)). Low-level resilience mostly increased in the central regions of Malayer. The northern and eastern regions showed one-floor parts in the realm of high-level resilience in Malayer. The results of two-floors and three floors show a moderate level of resilience in the central and outlying regions of Malayer by considering a decrease in the urban population distribution in Malayer (Figure 3(a)).

To analyze the spatial matrix of urban parts’ granularity parts, we described spatial dimensions based on open spaces for escape and refuge, relief operations and temporary accommodation, etc. We analyzed the smaller the area of segmented parts based on particular land use (Figure 3(b)). It showed that smaller areas of segmented parts in particular land use had a decreasing resilience in spatial directions. The distribution of a decrease in resilience differed from 0 to 400 m and more (Figure 3(b)). The increase in spatial directions (400 m and more) in the outer parts was higher than the

\[
D_i^{-} = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_{ij})^2}, \quad i = 1, \ldots, m
\]  

(7)

Finally, the value of the index \( i \) fluctuates between \( 0 \leq C_i \leq 1 \), \( C_i = 1 \) represents the highest rank (priority), and \( C_i = 0 \) represents the lowest rank (priority).

\[
C_i = \frac{D_i^{-}}{D_i^{-} + D_i^{+}}
\]

(8)

**Figure 3.** Spatial distribution of buildings indexes in Malayer city.
central parts of Malayer. It showed a decrease in the resilience distribution from the outlying regions to the central regions in Malayer (Figure 3(b)).

We used the building density to study the resilience rate of urban settlements in Malayer (Figure 3(c)). The results revealed that the spatial distribution of building density was different spatial scales. The building density change revealed that it varied the building density percentage of less than 5% to 65%, displaying that the resilience rate on urban settlements was different (Figure 3(c)). Also, the resilience rate on urban settlements showed broad changes in Malayer, hence, the resilience rate varied from low-level resilience in the outlying parts to high-level resilience in the outer parts of Malayer (Figure 3(c)).

All the resilience changes based on high seismic vulnerability suggested that the resilience rate and its effects were significant in Malayer. According to the age of buildings concept, prolongation of buildings’ life span, and consequently the increase in their burnout, reduction in their resilience, show a relative life expectancy for buildings in 30 years in Iran. Resilience changes based on the age of buildings in Malayer showed a decreasing pattern from outlying parts to the central parts, and the high-level resilience regions developed in out-central regions, gradually creating a relatively high-level resilience realm (Figure 3(d)). The variability in the spatial distribution of buildings’ age (less than 10 to over 30 years) in Malayer showed a decrease in the resilience distribution from the central regions to outlying regions in Malayer (Figure 3(d)).

We studied the assessed quality of materials of the buildings, both type and distribution, based on the resilience rate modeling of urban settlements (Figure 4(a,b)). The results show that residential buildings made of unsustainable materials such as clay, woods were increasing Malayer city (Figure 4(a)). The assessed quality of materials of the buildings showed a decreasing rate of resilience on urban settlements based on materials distribution of unsustainable such as clay in the central regions of Malayer (Figure 4(a,b)). It also shows that the unsustainable quality of materials had depended on the climatic conditions of each region.

We assessed access to health centres both time and distance based on the estimating of the resilience rate on urban settlements (Figure 4(c)). The findings show that the distance of health centres was different in Malayer city (Figure 4(c)). The estimated distance of health centres showed a different trend of resilience in urban settlements based on distance distribution in Malayer (Figure 4(c)). We observed that the health centres’ distance distribution was decreasing from the central regions to outer regions in Malayer. However, urban settlements’ resilience rate showed an increasing pattern from outlying regions to the central regions in Malayer (Figure 4(c)).

To analyze the resilience rate of urban settlements, we studied spatial distribution based on access to fire stations in Malayer. We analyzed the access to fire stations based on land use patterns (relief) (Figure 4(d)). It shows the distance of fire stations based on relief had a decreasing trend for resilience in spatial directions from the central parts to outer parts in Malayer. However, the resilience rate on urban settlements based on fire stations showed a decreasing pattern from outlying regions to the central regions in Malayer (Figure 4(d)).

Figure 4(e) shows access to open spaces in Malayer. Access to open spaces will be different, and results show an increase based on open spaces in the eastern regions of Malayer (Figure 4(e)). Based on access to open spaces, the resilience rate on urban settlements showed an increasing pattern in the eastern regions of Malayer (Figure 4(e)).

Urban networks and accesses can play a decisive role in the cities’ physical framework mapping. Any crisis management service depends on a dynamic, fluid, and active network of streets. If accesses, like corridors during earthquakes, are blocked, it will be difficult and even impossible to service the injured. Therefore, urban street network gridlocks should be able to meet the needs of crisis, and this is because of the design of the appropriate and optimal road network as a pillar of the development of land use density and the future role of cities determined in perspective. Figure 4(f) reveals access to streets in Malayer. Access to the streets will play a unique role, and results show an increase in the southwestern and eastern regions of Malayer (Figure 4(f)). Based on access to streets, the resilience rate on urban settlements showed an increasing trend in the southwestern and eastern regions of Malayer (Figure 4(f)).

We estimated access to educational centres, access to public green spaces, population density, and access to shelters and temporary accommodation centres, both patterns and distribution based on the estimating of the resilience rate on urban settlements in Malayer (Figure 5). We used to access educational centres in the resilience rate of urban settlements in Malayer (Figure 5(a)). The results showed that access to educational centres was significantly different based on pattern and distribution. The access to educational centres revealed that the uniform distribution was in all parts displaying that it distributed the educational centres (Figure 5(a)). Based on access to educational centres, the resilience rate on urban settlements showed an
increasing trend in Malayer (Figure 5(a)). Access to green and open spaces: Public open spaces include parks and public green spaces, sports fields, gardens, and farmland within a city and arid area, having the potential for sheltering, evacuating, and accommodating the injured. The pattern of open and green spaces throughout the urban texture surface of residential areas is an essential factor in increasing the texture during an earthquake. The position and level of open spaces are useful in the resilience against an earthquake. We assessed the access to green spaces, both distribution and distance, based on the estimating of the resilience rate on urban settlements (Figure 5(b)). The results show that access to green spaces was a different
distribution in Malayer city (Figure 5(b)). The estimated distribution of green spaces showed a different trend of resilience in urban settlements based on the distribution pattern in Malayer (Figure 5(b)). We noticed that the distribution of green spaces was increasing in the northeastern regions of Malayer. However, the resilience rate on urban settlements showed a decreasing pattern from northeastern regions to the central regions in Malayer (Figure 5(b)).

Population density refers to the population per unit area and usually, the population density of a city, population density in a neighbourhood, as an indicator used in urban areas as gross residential density (GRD). This indicator shows the population load during an earthquake. As this indicator rises, the rate of sheltering, servicing, and relieving decreases. Therefore, we consider population density to assess resilience levels. We measure the population density based on the estimating of the resilience rate on urban settlements (Figure 5(c)). The results show population density as a unique value in Malayer city (Figure 5(c)). The estimated population density showed a different trend of resilience in urban settlements based on the distribution pattern in Malayer (Figure 5(c)). We observed that the population density was increasing in the southwestern parts and central parts of Malayer. However, the resilience rate on urban settlements showed a decreasing pattern in the southwestern parts and central parts of Malayer (Figure 5(c)).

Access to shelters and temporary accommodation centres is a factor for providing accommodation and services to post-earthquake victims. Establishing relief and rescue bases and providing emergency services in the early stages of the crisis and other day-to-day services and livelihoods in the next stages is vital. We determine access to shelters and temporary accommodation centres based on the estimation of the resilience rate on urban settlements (Figure 5(d)). The results show that access to shelters and temporary accommodation centres was a distinct pattern in Malayer city (Figure 5(d)). The estimated access to shelters and temporary accommodation centres showed a different distribution of resilience in urban settlements in Malayer (Figure 5(d)). We observed that access to shelters and temporary accommodation centres increased in the eastern parts of Malayer. However, the resilience rate on urban settlements showed an increasing pattern in the eastern parts of Malayer (Figure 5(d)). Regarding the resilience of land uses in terms of compatibility and incompatibility in areas exposed to earthquakes, damages exposed to them is in question, so that establishing and uses with high potentials for being damaged
(via blasting, disrupting the function of other land uses, etc.) along with other land uses such as residential, commercial, office, ones, reduces resilience. We should identify the measures needed to prevent or mitigate the resulting crisis. The estimated distance from gas stations showed a distinct resilience pattern in urban settlements in Malayer (Figure 6(a)). We observed that the distance from gas stations was decreasing in the southwestern and southern parts of Malayer. However, the resilience rate on urban settlements showed a decreasing pattern in the southwestern and southern parts of Malayer (Figure 6(a)). The slope is another decisive factor in residential buildings’ resilience, facilitating against natural factors, including earthquakes. One of the secondary events that may occur after an earthquake is liquefaction based on two factors of soil type and slope in an area. We assessed the earth slope in both amount and direction based on the estimating of the resilience rate on urban settlements (Figure 6(b)). The results show that the earth slope was a diverse distribution in Malayer city (Figure 6(b)). The estimated distribution of earth slope showed a different trend of resilience in urban settlements based on the earth slope pattern in Malayer (Figure 6(b)). We noticed that the distribution of the earth slope was decreasing in the northeastern regions of Malayer. However, the resilience rate on urban settlements showed a decreasing pattern from northeastern regions to the southern and central regions in Malayer (Figure 6(b)). Distance from faults and flood-prone areas, the less the distance of buildings from faults and flood-prone areas are, the less resilience is, and vice versa. We assessed the distance from faults and flood-prone areas based on the estimating of the resilience rate on urban settlements (Figure 6(c,d)). The results show that the flood-prone was a uniform distribution in Malayer city (Figure 6(c)). The estimated distribution of flood-prone showed a similar trend of resilience in urban settlements based on the flood-prone pattern in Malayer (Figure 6(c)). We noticed that the distribution of flood-prone was a related pattern in Malayer. However, the resilience rate on urban settlements showed a related pattern in Malayer (Figure 6(c)). We assessed the distance from faults based on the estimating of the resilience rate on urban settlements (Figure 6(d)). The results show that the distance from faults was a diverse distribution in Malayer city (Figure 6(d)). The estimated distribution of distance from faults showed a different trend of resilience in urban settlements based on the distance from fault pattern in Malayer (Figure 6(d)). We observed the distribution of distance from faults with different effects in Malayer. However, the resilience rate on urban settlements showed a decreasing pattern from northeastern regions to the southwestern and central regions in Malayer (Figure 6(d)).

The standard analysis explores the positive and negative indicators based on the resilience rate of urban settlements in Malayer. The indicators of positive are

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**Figure 6.** Spatial distribution of earth indexes in Malayer city.
to increase the amount for resilience in a more favourable situation and include the following criteria: distance from faults, quality of buildings, distance from flood-prone areas, quality and type of building materials, distance from gas stations, building age, building density, population density, number of floors, and granularity of urban parts. Negative indicators comprise earth slopes, access to temporary accommodation and shelters, access to streets, access to green spaces, access to health centres, access to public open spaces, access to fire stations, and access to training centres are indicators that if their degrees fall, the sites determined for resilience are more appropriate. After the normalization process, the value values of the criteria are between zero and one, which in the positive index and negative zero indicators represents the lowest value and the one with the highest value (Table 2). We plotted the effects of the distance from the negative ideal solution based on the estimating of the resilience rate on urban settlements (Figure 7). The results show that the distance from the negative ideal solution was a varied distribution in Malayer city (Figure 7). The estimated distribution of distance from the negative ideal solution showed a different trend of resilience in urban settlements based on the distance from the negative ideal solution pattern in Malayer (Figure 7). We observed that the distribution of the distance from the negative ideal solution was a distinct pattern in Malayer. However, the resilience rate on urban settlements showed a decreasing pattern in the distance from the negative ideal solution from northeastern parts to the southwestern and central regions in Malayer (Figure 7). We mapped the effects of the distance from the positive ideal solution based on assessing the resilience rate on urban settlements (Figure 8). The results display that the distance from the positive ideal solution was a diverse distribution in Malayer city (Figure 8). The assessed distribution of distance from the positive ideal solution showed a distinctive pattern of resilience in urban settlements based on the distance from the positive ideal solution pattern in Malayer (Figure 8). We reflected that the distribution of the distance from the positive ideal solution was a distinct pattern in Malayer. However, the resilience rate on urban settlements showed an increasing pattern distance from the positive ideal solution from northeastern regions to the southwestern regions in Malayer (Figure 8).

We analyzed the effects of the spatial resilience model based on assessing the resilience rate on urban settlements using TOPSIS in Malayer. We used un-scaled matrix coefficients in the weights of indicators. In this step, based on the opinions of 25 experts’ specialists in urban planning, calculated the weight of each layer based on Analytic Hierarchy Process (AHP) through Expert Choice 2011 software, and analyzed each of the standard layers in GIS. We analyzed high-weight layers (Table 3). The results show that among the criteria affecting urban resilience of Malayer, the criterion of access to temporary accommodation and shelters with a score of 0.116 is the most significant, and the criterion of distance from the gas stations with a score of 0.018 has the lowest significance in the experts’ opinions. After preparing the data, normalization and weighting criteria combined. At this stage, we calculate the interval between each layer with positive and

| Indicators                                      | Criteria                                      | Standardization type | Criteria features and qualitative value |
|------------------------------------------------|-----------------------------------------------|----------------------|----------------------------------------|
| Physical                                       | Granularity of urban parts                    | Positive             | 1: 0–100 meters; 2: 101–200 meters; 3: 201–300 meters; 4: 301–400 meters; 5: 401 meters and more. |
|                                                | Number of floors                              | Positive             | 1: four floors and more; 2: three floors; 3: two floors; 4: one floor; 5: No construction. |
|                                                | Age of buildings                              | Positive             | 1: 31 years and more; 2: 21–30 years; 3: 20–11 years; 4: 0–10 years; 5: no construction. |
|                                                | Building density                              | Positive             | 1: 65–45%; 2: 25–45%; 3: 5–25%; 4: Less than 5%. |
|                                                | Building quality                              | Positive             | 1: Destruction; 2: repair; 3: maintenance; 4: under construction; 5: No construction; |
|                                                | Building material quality                     | Positive             | 1: other (adobe and clay) 2: brick and clay; 3: brick and iron; 4: metal; 5: concrete. |
| Access                                         | Access to streets                             | Negative             | As the access to the street grows, resilience increases. |
|                                                | Access to green spaces                        | Negative             | As the access to green space grows, resilience increases. |
|                                                | Access to fire stations                       | Negative             | As the access to fire stations grows, resilience increases. |
|                                                | Access to health centres                      | Negative             | As the access to health centres grows, resilience increases. |
|                                                | Access to educational centres                 | Negative             | As the access to educational centres, resilience increases. |
|                                                | Access to open spaces                         | Negative             | As the access to open spaces grows, resilience increases. |
|                                                | Access to shelters and temporary accommodation centres | Negative             | As the access to shelters and temporary accommodation centres grows, resilience increases. |
| Area                                           | The distance from gas stations                | Positive             | As the distance from gas stations increases, resilience increases. |
| Social                                         | Population density                            | Positive             | 1: 400–500 people per hectare; 2: 300–400 people per hectare; 3: 200–300 people per hectare; 4: 100–200 people per hectare; 5: No population. |
| Natural                                        | Earth slope                                   | Negative             | As the Earth’s slope increases, resilience decreases. |
|                                                | Distance from faults                          | Positive             | As the distance from faults increases, resilience increases. |
|                                                | Distance from flood-prone areas               | Positive             | As the distance from flood-prone areas increases, resilience increases. |
negative ideal solutions based on each of the positive and negative ideals. According to the results, in the positive ideal output layer (D), the spatial favourability rate varies within a range of 0.0354,771 to zero, depending on which pixels or areas whose values are closer to the zero coefficient, have higher resilience, and the closer the pixel value to the coefficient as 0.354771 is, the higher the resilience is. For the ideal negative layer (D-), we obtained spatial priority values ranging from 0.0517887 to 0. Pixels and areas with values of 0.0517887 have the highest resilience, and those with values of zero have the lowest resilience. Finally, we calculate the relative proximity to the ideal solution (Figure 9). To analyze the last map, we separate the physical area based on the pixels’ value, and we calculate the area of each of the priorities. In this step, we determined the resilience degree based on C values in Malayer. However, in this case, the options are all the map pixels (28,390 pixels). In Figure 9, the range of value obtained from the model in measuring the resilience of Malayer is between zero and one; we should note that the pixel’ value close to 1 shows the amount of high-density algorithm and the higher the amount of received pixel value to zero, show as the lower resilience of that pixel. We categorized the results of the TOPSIS model into four conventional classes, including very low resilience, appropriate resilience, low resilience, and high resilience. Of the total area of Malayer, 91.69% of its texture has excellent and high resilience. In (Table 4), expresses the area of the four classes derived from the model in terms of m² and percentage. The results show that 2.17% of the city’s texture shows a very low resilience, 6.14% of it has low resilience, 25.67% has appropriate resilience, and 66.02%

**Figure 7.** Distance from the negative ideal solution.

**Figure 8.** Distance from the positive ideal solution.
of the texture has high resilience. We achieve these outputs according to the status of the indicators and their weight. The resilience of this city is the existence of massive open spaces and vast open spaces around the city. It can also be said that, according to experts and weights derived from the AHP model, access to shelters, distance from faults, access to fire stations, distance from flood-prone areas, and access to open spaces are essential factors that have led to higher privileges and these values have made Malayer shows a resilient city. There is a difference in the model's area and the actual area of the city because of the difference in pixels.

This paper assesses the concept of urban resilience and highlights the Rockefeller Foundation's efforts to create resilience throughout the world. The study described Rotterdam as one of the first cities in urban resilience, stating that it is preparing itself for climate change and sustaining the city. In this research, researchers have drawn on the difference between urban resilience and urban sustainability. They have concluded that the rational development of the city is possible only when both resilience and sustainability exist. According to the studies, show the difference between the present research and other studies that in this research, by creating a suitable model and applying a variety of spatial data, and conducting relevant analyzes in the GIS and the multiple-criteria decision-making model (TOPSIS), the evaluation of resilience of Malayer is at stake. The distance as far as 100 km away from the city shows the principal and medium-sized faults as a dangerous source. 8.31 percent of the urban texture has low resilience. There are more pixels in the central parts of the city, where there are burnout buildings, educational centres, health care facilities, and temporary accommodation. It matches the old texture of Malayer with 110 hectares with the central core of this city and includes all the neighborhoods of the old city texture. Conditions such as impassability and inefficiency of the urban communication network, the

| Table 3. Weighting criteria for measuring urban resilience using the AHP method |
|---------------------------------|-----------------|-----------------|-----------------|
| Criteria                        | Weight          | Criteria        | Weight          |
| The granularity of urban parts  | 0.030           | Access to health centres | 0.056 |
| Number of floors                | 0.050           | Access to educational centres | 0.030 |
| Age of buildings                | 0.042           | Access to open spaces | 0.058 |
| Building density                | 0.022           | Access to shelters and temporary accommodation centres | 0.116 |
| Building quality                | 0.059           | The distance from gas stations | 0.018 |
| Building material quality       | 0.058           | Population density | 0.022 |
| Access to streets               | 0.052           | Earth slope     | 0.051 |
| Access to green spaces          | 0.070           | Distance from faults | 0.095 |
| Access to fire stations         | 0.091           | Distance from flood-prone areas | 0.085 |

| Table 4. Areas and values of pixels in TOPSIS |
|-----------------------------------------------|-----------------|-----------------|-----------------|
| Qualitative value                            | Pixel value     | Area (m²)       | Area percentage |
| Very low resilience                          | 0–0.25          | 513,157.33      | 2.17            |
| Low resilience                               | 0.26–0.5        | 1,451,637.61    | 6.14            |
| Appropriate resilience                       | 0.51–0.75       | 6,065,339.88    | 25.67           |
| High resilience                              | 0.76–1.0        | 15,599,502.33   | 66.02           |
heterogeneous distribution of infrastructure and open spaces of the city, the high level and low quality of buildings, granularity and plenty of small parts in the worn-out texture of the city and one case that have reduced resilience in the city. Residential and urban texture in this section, because of its historical properties, can suffer from the acute physical disruption in the face of imbalances caused by the earthquake and create a city life crisis. In such a situation, the risk of an earthquake seriously threatens all this worn-out area, and at the moment of an earthquake, it becomes a major catastrophe. Therefore, from the perspective of crisis management, this area can be vulnerable to accidents, while ignoring this issue, the most useful rescue and relief efforts cannot prevent earthquake disasters. The general slope of the city decreases from the center towards the south and southwest of the city. The slope decrease, especially in the western part, causes problems with the disposal of this area’s surface waters. This could be a problem in the event of a flood in the city. It is possible to reduce the risk of flooding and the accumulation of surface water in this area using the principal flood control measure, including tree plowing, construction of flood sewers, reservoirs, and flood channels. Brick-making furnaces in the city’s southwest cover an area of 600 hectares and, because of the activity of several years, destroyed the land situation in the area. Because of excavations, excavations with a height of over 10 meters in the area, lead to soil degradation, erosion, and soil thrust that may reduce its resilience. By creating a green belt surrounding the area or transferring brick furnaces to the place and restoring the remains of land degradation, it can compensate this for problem. There is arid land or abandoned spaces in the central texture of the city. The area of this land use covers 5,368,077 m², which is about 24 percent of the total area of the city. These lands can plan the development of the service area of Malayer in relief services.

4. Conclusion

This study shows a very high resilience capability for most academic disciplines and reflects the growing need for these sciences to resilience. Cities are no exception to their sustainability and need resilience. Nowadays, the analysis and increase of resilience to natural disasters has become an essential and widespread field, which currently discusses the simultaneous and reciprocal movement of sustainable development and disaster management to increase resilience. The analysis and enhancement of resilience in human and environmental systems against natural disasters in the path to achieving sustainable development are of particular importance. In this study, to assess the resilience of Malayer used indicators, and factors affecting resilience. Then, we compare criteria by experts and experts using the hierarchical analysis process. As a next step, the decision matrix recorded using TOPSIS. The results show that the essential criterion for the resilience of the city of Malayer is the criterion of access to temporary shelters and shelters with a score of 0.116, and the criterion of distance from the pump station with a score of 0.018 is the least important criterion for experts. We also classified the results of the TOPSIS model into four conventional classes, including high resilience, proper resilience, low resilience, and very low resilience. The results show that 2.17% of urban texture covers very low resilience, 6.14% low resilience, 25.67% proper resilience, and 66.02% high resilience. The reason for the high resilience of the city is the existence of arid lands and vast open spaces around the city. According to experts and weights derived from the AHP model, access to accommodation and shelters, distance from faults, access to fire stations, distance from flood-prone areas, and access to open spaces are important factors. As a result, their scores of higher values have made Malayer into a resilient city.

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PUBLIC INTEREST STATEMENT

Environmental resilience has become one of the most common subjects in almost all research areas. This study reviews environmental resilience, the natural, accessibility, privacy, and social indices for reducing environmental damages. We use the decision-making matrix, standardization of indicators based on fuzzy method, ideal indicators, matrix coefficient change based on the weight of indices, the ideal positive and negative solutions, distance measure, and the relative proximity of the ideal solution using multi-criteria decision-making method (MCDM) in Malayer city, Iran. The aim of this review article is to introduce awareness amongst the use of various indices on environmental resilience in environmental planning and management.

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