Article
Evaluating Natural Hazards in Cities Using a Novel Integrated MCDM Approach (Case Study: Tehran City)

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Abstract: Tehran, the capital of Iran, is the largest and most populous city in Iran, which is of great importance due to its large population and abundant infrastructure. One of the most critical issues in this city is its need for resilience against all kinds of threats, including natural hazards, because its development was not based on territorial geography. In other words, in developing this 700 square kilometer area, attention has yet to be paid to its different zones. Different zones include the mountains, Shemiranat’s alluvial cone area, the Tehran plain, etc. Main and minor faults, surface and underground water resources of the land, differences in formations between various parts of the land, the microclimate of the land in its multiple aspects, local and synoptic air currents, etc., have not been influential in urban development. The most crucial goal of this study is to identify and screen natural hazards in Tehran to improve this city’s resilience by introducing a novel integrated MCDM method based on ANP and The Combined Compromise Solution method with Maximum Variance (MV-CoCoSo). Therefore, to increase the strength of Tehran against these disasters, the natural hazards of Tehran must first be identified and ranked. In this regard, practical criteria for evaluating Tehran’s resilience were identified using library resources and the formation of expert groups. Then, using the ANP method, the comparative weightings of these effective criteria was investigated. Based on the results obtained, the disaster consequence criterion had the highest importance with a weight of 0.4361, followed by the disaster severity scale criterion with a weight of 0.2371, and the secondary threat possibility criterion (with a weight of 0.1232) was ranked third. Finally, using the MV-CoCoSo method, the natural hazards of Tehran city were classified based on the evaluated criteria. Tehran City’s three significant disasters were earthquakes, floods, and landslides. In addition, two experiments were designed to assess the robustness of the research methodology.

Keywords: natural hazard; analysis network process (ANP); MV-CoCoSo; cities; resilience

MSC: 20F10; 62J15; 62P30

1. Introduction

Since the beginning of creation, man has always faced insecurity and threat. Man has always tried to secure his life, property, living space, and food against natural hazards, and build a safe habitat. These structures may be affected by excessive applications and natural hazard risks during their lifetime, resulting in decreased structural integrity. Natural hazards can be land-based (e.g., earthquakes), water-based (e.g., river floods), atmospheric (e.g., tornadoes), biological (e.g., pandemics), extraterrestrial-based (e.g., comet strikes), or any combination of these (e.g., undersea earthquake and tsunami). Although these disasters differ, their impacts on humans and habitats are similar. All natural hazards can cause loss of life and damage to humans and their possessions, disturbing people’s daily lives [1].

In natural hazards, there is no will or grudge. For example, it is not the case that the earthquake occurrence and the destruction of buildings will continue so much as to lead
to the destruction of the building finally out of resentment or hostility. Hence, another characteristic of natural hazards is their relentless nature; out of more than 40 natural hazards, 31 types have been recorded in Iran, from destructive earthquakes to floods, and this variety makes studying critical conditions necessary [2].

In general, there are two types of strategies to deal with natural hazards: prediction strategies and resilience strategies. The first is used to deal with known problems and dilemmas, and the second is used to deal with unpredictable problems.

Resilience improves society’s planning, preparation, and ability to deal with unwanted effects after accidents, and restoring and enhancing the community’s damaged situation regarding social, economic, ecological, and physical aspects [3]. As mentioned, one of the ways to reduce the damage of natural hazards is investing to increase resilience. Increasing resilience is the reason we have better predictions and better plans to reduce the damage caused by accidents. Awareness and preparation are better than waiting for an accident and compensating for the consequential losses. In this regard, to increase cities’ resilience against natural hazards, it is necessary to first identify these threats in a target city and then organize them. There has been a lot of research in the field of natural hazards, the most important of which are the following: Cui et al. [4] worked on the scientific challenges of research on natural hazards and disaster risk, and consequently identified upcoming challenges of natural hazards for China between 2025 and 2035. Jalali [5] researched new approaches to threats and reviewed existing categories in this area. Caldera and Wirasingh [1] studied a universal severity classification for natural hazards. Below et al. [6] worked on disaster category classification and peril terminology for operational purposes. Toya and Skidmore [7] worked on the impacts of natural hazards on economic development. They found that countries with higher income, higher educational attainment, greater openness, more complete financial systems, and smaller government experience fewer losses from natural disaster. Cavallo and Noy [8] worked on the economics of natural hazards, then examined some relevant policy inquiries and followed up with projections about the likelihood of future disasters. The paper ends by identifying significant gaps in the field literature. Vousdoukas et al. [9] assessed climatic and socioeconomic influences on future European coastal flood risk.

Furthermore, some researchers assessed the risk of such disasters at both global and regional scales [10–14]. Cui et al. evaluated the risk of simultaneous debris flows in mountain townships [15], while Shroder et al. discussed the risk of hazards and disasters in societies [16].

This paper identifies and evaluates natural hazards in Tehran city to increase the resilience of Iran’s capital against possible future risks, using a novel integrated MCDM method. Tehran has a population of about 9 million residents and includes the country’s main decision-making centers; any possible danger will result in many injuries and financial damages.

Most previous research has investigated the various dimensions of natural hazards or focused on only one possible natural hazard. Few studies have investigated the general intensity and power of natural hazards in important cities, including the capitals of countries. Therefore, in this research, we aim to future decision making by considering various natural hazards, and prepare Tehran city to deal with the most probable of them.

The types of natural hazards in Tehran city were identified using appropriate techniques. The criteria of threat evaluation were then designated using library resources, and the weight of each criterion was determined through the ANP method. Finally, using MV-CoCoSo, these threats were ranked. Figure 1 shows the methodology flowchart.

As a result of this research, the following parts are included: Section 2 describes the literature review on natural hazards and MCDM application. The types of natural hazards are introduced in Section 3. Section 4 explains the research methodology. Section 5 presents the research criteria. Section 6 contains the implementation of the research methodology and its results. In Section 7, experiments are described for research validation. Finally, Sections 8 and 9 provide managerial implications and research conclusions.
Figure 1. Schematic representation of research methodology for assessing the natural hazards of Tehran.

2. Literature Review

This section presents a literature review on natural hazards and the application of multicriteria decision making in facing them. Table 1 shows the related literature review.

Table 1. Literature review on natural hazards and the application of MCDM.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Method(s)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tella and Belagun</td>
<td>Fuzzy AHP–GIS</td>
<td>Spatial assessment of flood susceptibility in Ibadan, Nigeria</td>
</tr>
<tr>
<td>Souissi et al.</td>
<td>AHP–GIS</td>
<td>Developing a flood hazard susceptibility map of the Gabes region</td>
</tr>
<tr>
<td>Salehpour et al.</td>
<td>IIM–AHP–TOPSIS–VIKOR</td>
<td>Producing landslide susceptibility maps (LSMs) in the Alamut watershed, Iran</td>
</tr>
<tr>
<td>Reis et al.</td>
<td>iSECA</td>
<td>Development of a drought vulnerability index in São Paulo and Ceará, Brazil</td>
</tr>
<tr>
<td>Hoseinzade et al.</td>
<td>VIKOR–PROMETHEE II</td>
<td>Landslide evaluation</td>
</tr>
<tr>
<td>Akay</td>
<td>Fuzzy logic–AHP–TOPSIS–VIKOR</td>
<td>Providing the flood hazards susceptibility map of an area in Turkey</td>
</tr>
<tr>
<td>Mastouri et al.</td>
<td>AHP</td>
<td>Introducing a landslide susceptibility map in the Arabdagh forests, Golestan Province, Northern Iran.</td>
</tr>
<tr>
<td>Poddar et al.</td>
<td>AHP</td>
<td>Developing a flood-susceptible map in the Teesta River basin of West Bengal, India.</td>
</tr>
<tr>
<td>Lyu and Yin</td>
<td>AHP-interval FAHP–ANP</td>
<td>Assessing multihazard risks in Hong Kong</td>
</tr>
<tr>
<td>Jamali et al.</td>
<td>DEMATEL–ANP</td>
<td>Evaluating the urban resilience of Tehran</td>
</tr>
</tbody>
</table>
As is evident in Table 1, less research has been done to identify and evaluate the essential and influencing factors on the severity and possibility of natural hazards. Furthermore, the possible risks for a metropolis with the dimensions considered in this research have yet to be investigated.

3. Kinds of Natural Hazard in Cities

In this section, to determine which specific natural hazards threaten Tehran, a three-stage procedure was implemented:

- Examining internal and external library resources.
- Extracting the opinions of experts and specialists in the field of threat science.
- Examining the records of occurrence of natural hazards in a case study.

Next, by summarizing these three stages, eight natural hazards were selected for evaluation in Tehran city: landslides, land subsidence, dust events, earthquakes, floods, climate changes, droughts, and storms. These eight natural hazards are considered research options, and each of these is briefly defined below.

a. Landslide (A1)

A landslide is a complex geological phenomenon consisting of a series of layers with differing and gradational physical properties that often occur in association with road-cut slopes [27].

b. Land Subsidence (A2)

Land subsidence includes gentle down warping and the sudden sinking of discrete segments of the ground’s surface. The extraction of fluids such as water, crude oil, and of natural gas from subsurface formations is the leading cause of land subsidence [28].

c. Dust Phenomenon (A3)

Dust storms are natural atmospheric phenomena that have adverse effects due to dust spread, low visibility, accidents, and their impacts on human activities and health. A dust storm is a complex process that is influenced by the action and effects of atmospheric systems; mainly, conditions such as high wind speed, bare soil, and dry air cause it [29].

d. Earthquake (A4)

An earthquake is any sudden shaking of the ground caused by the passage of seismic waves through the Earth’s rocks. Seismic waves are produced when some form of energy stored in Earth’s crust is suddenly released, usually when rock masses straining against one another suddenly fracture and slip [30]. The necessity of paying attention to natural hazards such as earthquakes in order to reduce the damage caused by them has been emphasized by many researchers in many studies [31–37].

e. Flood (A5)

Flooding is the partial or complete inundation of normally dry land areas with the overflow of inland or tidal waters that arises from either source’s unusual and rapid accumulation; e.g., from runoff of surface waters. Such submersion can be either irreversible or temporary. In other words, a flood is an overflow of water that usually submerges dry land. Floods are an area of study in the discipline of hydrology. They are the most common and widespread natural severe weather event [38].

f. Climate change (A6)

Climate change is a long-term change in a region’s typical or average weather. In the last few decades, industrial and human activities have led to gradually accelerating climate changes, including an annual incremental increase in the average surface temperature, defined as climate change. Climate change also has noticeable negative impacts on other parts of the planet, such as changes to ecosystems, desertification, rise in sea level, flooding, and drought [39].
Drought ($A_7$)

Drought is an intense and persistent shortage of precipitation instigates. Droughts vary by multiple dynamic dimensions, including severity and duration [40].

Storm and tornado ($A_8$)

This hazard refers to a strong, dangerous wind that forms itself into an upside-down spinning cone and can destroy buildings as it moves across the ground [41].

4. Methodology

This study identified the fundamental criteria for evaluating natural hazards in cities using library resources. All the proposed measures were then extracted for openings through interviews with experts in civil engineering, crisis management, and urban design. In the next step, a questionnaire was distributed among 21 experts to survey their weighting of the effective indicators. The degree of importance of each criterion was obtained by the 9-point Likert scale method using a group decision-making technique based on a paired comparisons model. Eventually, priorities and the final weight of criteria were determined using ANP technique. ANP provides the chance to observe both interaction and feedback both within clusters of elements (inner dependence) and between clusters (outer dependence). In order to check the validity of the questionnaire, Cronbach’s alpha test was used [42]. Finally, MV–CoCoSo was used to identify the most dangerous natural hazards for Tehran. MV–CoCoSo benefits from a maximum variance optimization model, which results in more accuracy than alternative prioritizations. Furthermore, for the first time, the combination of ANP–MV–CoCoSo and BWM–MV–CoCoSo and their sensitivity analysis are introduced in this research.

a. ANP method

The analytic network process (ANP) is a multicriteria decision-making method used to determine the weight of the criteria and select the optimal option based on pairwise comparisons that also consider the internal relationships between decision-making elements [43]. The purpose of this method is to structure the decision-making process according to a scenario affected by multiple independent criteria [44]. ANP, a generalization of AHP, was first proposed by Saaty in 1996. In cases where the lower levels affect the upper levels, or where the elements in the same level are not independent, the AHP method cannot be implemented anymore. For this reason, Saaty proposed the ANP method [45]. ANP is a more general form of AHP, and does not need its hierarchical structure. As a result, it shows more complex relationships between different decision levels in a network form, in addition to considering the interactions and feedback between criteria and alternatives. In the hierarchical analysis method, the dependencies must be linear (from top to bottom or vice versa) if the dependency is two-way; that is, if the weight of the criteria depends on the weight of the options, and the weight of the options depends on the weight of the criteria. The problem arises out of the hierarchical state, forming a network or non-linear system. In this case, hierarchical rules and formulas cannot be utilized to calculate the weight of the elements. Instead, network theory should be used to calculate the weight of elements. The most straightforward network is made of several clusters with elements inside them.

Among the latest research conducted using the ANP method, the following research can be mentioned: Magableh and Mistarihi used the integrated ANP–TOPSIS technique to evaluate supply chain problems and their solutions in the context of COVID-19 [46]. Rao used the DEMATEL–ANP integrated approach to improve the measurement of corporate sustainability indicators based on corporate social responsibility (CSR) reports [47]. Ozkaya and Erdin applied the ANP–TOPSIS combination to evaluate the considerable criteria in the context of smart and sustainable cities. Moreover, they prioritized 48 cities worldwide according to the assessed criteria [48]. Feng et al. developed an MCDM model based on DEMATEL, ANP, interval uncertainty, and VIKOR to optimize the reliability-based products according to environmental measures [49]. Tadić et al. used integrated fuzzy–ANP, fuzzy–DEMATEL, and fuzzy–VIKOR to select city logistics (CL) concepts suitable for
all engaged participants [50]. Wang and Tzeng used DEMATEL–ANP–VIKOR for brand marketing to create value and satisfy customer expectations [51]. Büyüközkan and Çifçi utilized fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS to evaluate green suppliers [52].

The steps of ANP are as follows [46,53]:

First, the formation of the network structure, criteria, subcriteria, and options are defined. Then, the clusters of elements are determined. The network is formed based on the relationship between the clusters, and between the elements within each cluster. There are a few different relationships that are effective. The direct effect may be considered a regular dependence in a standard hierarchy. Indirect effect dependency in a state that is not directly related must flow through another criterion or option. Another effect is the interaction effect itself. The last is the interdependencies between the criteria that make up the interaction.

4.1. Formation of Pairwise Comparison Matrices

Pairwise comparisons are performed according to either the criterion or subcriterion of the hierarchy of the system [53]. In paired comparison, decision makers compare two elements. They then determine the contribution of these practical factors to the result [46]. In ANP, as in AHP, pairwise comparison matrices are formed using the 1–9 scale of relative importance proposed by Saaty [46]. The relative importance scale 1–9 is presented in Table 2.

Table 2. The scale of relative importance.

<table>
<thead>
<tr>
<th>Degree of Importance</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
</tr>
<tr>
<td>5</td>
<td>Necessary or great importance</td>
</tr>
<tr>
<td>7</td>
<td>Powerful important</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Average value between adjacent scale values</td>
</tr>
</tbody>
</table>

According to Saaty’s research [44,45], a pairwise comparison matrix is generated using pairwise comparison values, and the local priority vector is computed by calculating the eigenvector:

\[ AW = \lambda_{eig}\omega \]  

In this equation, \( A, W \) and \( \lambda_{eig} \) are the pairwise comparison matrix, eigenvector, and eigenvalue, respectively. Moreover, according to Saaty, the normalization process for an approximate solution can be developed for \( \omega \) [54].

Based on the comparison of the factors, the following matrix is derived:

\[ A = [a_{ij}]_{n \times n}, i = 1, n; j = 1, n \]  

In order to calculate the significance distribution of factors, the following formulas are used:

\[ B_{i} = [b_{ij}]_{n \times 1}, i = 1, n \]  

\[ b_{ij} = \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \]  

\[ C = [c_{ij}], i = 1, n; j = 1, n \]  

\[ \omega_{i} = \frac{\sum_{j=1}^{n} c_{ij}}{n} W = [\omega_{i}]_{n \times 1} \]
4.2. Formation of Supermatrix and Limit Supermatrix

The general structure of the supermatrix is similar to the process of the Markov chain [54]. The global priority in a system with dependent effects is determined by assigning all local priority vectors to the supermatrix’s corresponding columns. Due to this, the supermatrix is a finite matrix, with each part representing a relationship between two elements. The long-term relative effects of the elements upon each other are obtained by increasing the power of the supermatrix. As a way to equalize the importance weights, the power of the matrix is increased to \( (k + 12) \), where \( k \) is a large number that can be chosen at random. The new matrix is called a super-limit matrix [55]. The compatibility of comparing elements is calculated as follows:

\[
D = [a_{ij}]_{n\times n} \times [\omega_i]_{1\times n} = [d_i]_{n\times 1}
\]

\[
E_i = \frac{d_i}{\omega_i}, i = 1, n
\]

\[
\lambda = \frac{\sum_{i=1}^{n} E_i}{n}
\]

\[
CI = \frac{\lambda - n}{n - 1}
\]

\[
CR = \frac{CI}{RI}
\]

In the above equations, CI, RI, and CR represent the consistency index, randomness index, and consistency rate, respectively. The compatibility of the paired matrix is checked with the compatibility index (CI). For acceptable consistency, the CI should be smaller than 0.10 [56].

b. MV–CoCoSo

By integrating three famous MCDM methods (WASPAS, SAW, and MEW), Yazdani et al. introduced a combined compromise solution (CoCoSo) as a MCDM technique to evaluate the desired options [57]. Recently, CoCoSo was utilized to assess the 5G industry in a fuzzy environment [58], transportation company selection [59], analysis of failure modes in wind turbines [60], and the selection and evaluation of industrial robots for the automobile manufacturing industry in a fuzzy environment based on Bonferroni functions [61]. Moreover, Lai et al. developed a revised CoCoSo model that maximizes global and local differences between alternatives while avoiding inconsistency in prioritization using a maximum variance optimization model [62].

The MV–CoCoSo algorithm is based on seven steps:

Step 1. Create the initial decision matrix.

By considering \( m \) alternatives and \( n \) criteria, the initial decision matrix is created to start the evaluation process.

\[
\begin{bmatrix}
c_1 & c_2 & \cdots & c_n
\end{bmatrix}
\]

\[
I = \begin{bmatrix}
a_{11} & a_{12} & \cdots & a_{1n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{m1} & a_{m2} & \cdots & a_{mn}
\end{bmatrix}
\]

\[
A_j = \begin{bmatrix}
a_{j1} & a_{j2} & \cdots & a_{jn}
\end{bmatrix}, j = 1, 2, \ldots, m; 
\]

Step 2. Normalize the initial data.

In order to normalize the initial decision matrix, Equations (13) and (14) are utilized:

\[
n_{ij} = \frac{a_{ij} - \min_{i} a_{ij}}{\max_{i} a_{ij} - \min_{i} a_{ij}} \text{ for the beneficial criteria}
\]

\[
n_{ij} = \frac{a_{ij} - \min_{i} a_{ij}}{\max_{i} a_{ij} - \min_{i} a_{ij}} \text{ for the non-beneficial criteria}
\]
\[ n_{ij} = \frac{\max_i a_{ij} - a_{ij}}{\max_i a_{ij} - \min_i a_{ij}} \quad \text{for the Cost criteria} \quad (14) \]

Step 3. Calculate the sum of the weighted comparability sequence \( S_i \) and power-weighted comparability sequences \( P_i \).

To obtain \( S_i \) and \( P_i \) values of each alternative, Equations (15) and (16) are used:

\[ S_i = \sum_{j=1}^{n} (w_j n_{ij}), \quad \text{for } i = 1, 2, \ldots, m \quad (15) \]

\[ P_i = \left( \sum_{j=1}^{n} (n_{ij})^w \right), \quad \text{for } i = 1, 2, \ldots, m \quad (16) \]

where \( (w_j) \) shows the weight of \( j \)th criteria.

Step 4. Calculate the relative weight of alternatives.

Three evaluation score blueprints are considered to accomplish this step for each alternative:

\[ k_{i1} = \frac{S_i + P_i}{\sum_{i=1}^{m} (S_i + P_i)}, \quad \text{for } i = 1, 2, \ldots, m \quad (17) \]

\[ k_{i2} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i}, \quad \text{for } i = 1, 2, \ldots, m \quad (18) \]

\[ k_{i3} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{\lambda(\max_i S_i) + (1-\lambda)(\max_i P_i)}, \quad \text{for } i = 1, 2, \ldots, m \quad (19) \]

Step 5. Normalize the evaluation score blueprints.

Three evaluation score blueprints need to be normalized according to Equation (20):

\[ k'_{ih} = \frac{k_{ih}}{\sum_{i=1}^{m} k_{ih}}, \quad \text{for } i = 1, 2, \ldots, m; \ h = 1, 2, 3 \quad (20) \]

where \( k_{ih} \) is the evaluation score blueprint of the \( i \)th alternative under the \( h \) aggregation scheme.

Step 6. Construct the maximum variance optimization model.

The following model is considered to carry out step 6:

\[ \max \frac{1}{m} \sum_{i=1}^{m} (k''_i - \frac{1}{m})^2 \]

s.t. \[ \sum_{i=1}^{m} k''_i = 1 \]
\[ k''_i \leq k''_i \leq k''_i \]

(21)

where \( k''_i^- = \min\{k'_{i1}, k'_{i2}, k'_{i3}\} \) and \( k''_i^+ = \max\{k'_{i1}, k'_{i2}, k'_{i3}\} \).

Step 7. Rank the alternatives.

In the final step, the options are ranked according to their \( k''_i \) values in descending order.

5. Research Criteria Identification

A conference meeting of research experts was held to identify the crucial criteria for choosing the natural hazards of Tehran city. Table 3 illustrates the number of experts based on their field and expertise.
Table 3. Experts group information.

<table>
<thead>
<tr>
<th>Variable</th>
<th>No.</th>
<th>Variable</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Civil Engineering</td>
<td>9</td>
<td>(3) Urban design</td>
<td>4</td>
</tr>
<tr>
<td>(2) Crisis management</td>
<td>7</td>
<td>(4) Top Managers</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4 shows the identified criteria to assess natural hazards in Tehran.

Table 4. Research criteria.

<table>
<thead>
<tr>
<th>Criteria</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>C₁</td>
<td>Disaster severity scale</td>
</tr>
<tr>
<td>C₂</td>
<td>Responsive capacity</td>
</tr>
<tr>
<td>C₃</td>
<td>Secondary threat platform</td>
</tr>
<tr>
<td>C₄</td>
<td>Threat history</td>
</tr>
<tr>
<td>C₅</td>
<td>Disaster consequence</td>
</tr>
<tr>
<td>C₆</td>
<td>Recovery time and process</td>
</tr>
</tbody>
</table>

a. **Disaster severity scale (C₁)**

This criterion shows the intensity of the disaster. The use of the Disaster Severity Scale allows researchers to classify previous hazards by scoring each disaster’s severity [63].

b. **Responsive capacity (C₂)**

This criterion shows how top management respond to crises and damages, and how they reduce the negative consequences of risks with an adequate and timely reaction along with a rapid assessment of infrastructure damage [64].

c. **Secondary threat possibility (C₃)**

This criterion refers to the possibility of a second threat occurring after the initial threat [65].

d. **Threat history (C₄)**

The frequency of disasters is the probability of the threat occurring in recent years and their intensity in the future [65].

e. **Disaster consequence (C₅)**

This criterion describes the extent of injuries, losses, and damages caused by the threat to manpower, equipment, and facilities and time. The severity of damages, injuries, and casualties includes primary and secondary damages within all dimensions of human, economic, social, time, mental and psychological forces, etc. [66]

f. **Recovery time and process (C₆)**

Disaster recovery is the maintenance or re-establishment of vital infrastructure and systems following a natural or human-induced disaster. Truthfully, disaster recovery needs time and pivotal policy implementation to provide the required ability to regain functions and continue critical infrastructure operations after the incident [67].

6. Results

a. **ANP result**

First, research criteria weights were determined by ruling out the interdependence among criteria [68]. For this, a pairwise comparison matrix was formed based on the
opinion of experts using Saaty’s scale of 1–9, which is shown in Table 4, from which the weight of the criteria is then calculated. The normalized eigenvectors matrix of this structure is presented in Table 5. A “zero” value in Table 5 indicates that there was no dependence between the two criteria, and the numerical values show the relative impact between the two criteria.

Table 5. The pairwise comparison matrix for criteria.

<table>
<thead>
<tr>
<th></th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>$C_6$</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>0.333</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>0.237</td>
</tr>
<tr>
<td>$C_2$</td>
<td>0.2</td>
<td>0.2</td>
<td>0.5</td>
<td>0.25</td>
<td>1</td>
<td>2</td>
<td>0.051</td>
</tr>
<tr>
<td>$C_3$</td>
<td>0.167</td>
<td>0.25</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0.123</td>
</tr>
<tr>
<td>$C_4$</td>
<td>0.125</td>
<td>0.167</td>
<td>0.333</td>
<td>0.167</td>
<td>0.5</td>
<td>1</td>
<td>0.032</td>
</tr>
<tr>
<td>$C_5$</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>8</td>
<td>0.436</td>
</tr>
<tr>
<td>$C_6$</td>
<td>0.25</td>
<td>0.5</td>
<td>0.333</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>0.119</td>
</tr>
</tbody>
</table>

Thus, according to the conditions of Tehran, disaster consequence ($C_5$), with a weight of 0.4361, took the first place in prioritization, followed by the disaster severity scale ($C_1$), with a weight of 0.2371. In third place was the secondary threat possibility ($C_3$), with a weight of 0.1232. With a weight of 0.1194, recovery time and process ($C_6$) was ranked fourth. Responsive capacity ($C_2$), with a weight of 0.018, was placed in the fifth rank. Finally, the category of threats history ($C_4$), with the obtained weight of 0.0323, was considered the least important criterion of this research. Tables 5 and 6 show the results of ANP implementation.

Table 6. Degree of relative impact for criteria.

<table>
<thead>
<tr>
<th></th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>$C_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>0</td>
<td>0.841</td>
<td>0.112</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$C_2$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.797</td>
<td>0</td>
</tr>
<tr>
<td>$C_3$</td>
<td>0</td>
<td>0</td>
<td>0.86</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$C_4$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>$C_5$</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.203</td>
<td>0</td>
</tr>
<tr>
<td>$C_6$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

b. MV–CoCoSo results

In the first step, the decision-making matrix is formed, which includes six decision-making indicators and eight main threats (options) of Tehran. This matrix, shown in Table 7, was the result obtained from the opinions of the highly qualified experts regarding the values of each option according to each criterion.

Table 7. Initial decision matrix for ranking natural hazards in Tehran.

<table>
<thead>
<tr>
<th></th>
<th>Cost Criterion</th>
<th>Benefit Criterion</th>
<th>Cost Criterion</th>
<th>Cost Criterion</th>
<th>Cost Criterion</th>
<th>Cost Criterion</th>
<th>Cost Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternatives</td>
<td>$X_1$</td>
<td>$X_2$</td>
<td>$X_3$</td>
<td>$X_4$</td>
<td>$X_5$</td>
<td>$X_6$</td>
<td></td>
</tr>
<tr>
<td>$A_1$</td>
<td>7.3</td>
<td>6.2</td>
<td>8.5</td>
<td>6.1</td>
<td>6.4</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>$A_2$</td>
<td>5.2</td>
<td>6.5</td>
<td>5.1</td>
<td>4.3</td>
<td>6.4</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>$A_3$</td>
<td>6.3</td>
<td>4.2</td>
<td>7.1</td>
<td>6.3</td>
<td>6.2</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>$A_4$</td>
<td>9.3</td>
<td>4.5</td>
<td>8.3</td>
<td>8.2</td>
<td>7.4</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>$A_5$</td>
<td>7.4</td>
<td>3.6</td>
<td>6.3</td>
<td>8.3</td>
<td>6.7</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>$A_6$</td>
<td>6.4</td>
<td>4.1</td>
<td>7.2</td>
<td>3.1</td>
<td>4.6</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>$A_7$</td>
<td>5.4</td>
<td>4.1</td>
<td>5.3</td>
<td>3.2</td>
<td>7.1</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>$A_8$</td>
<td>4.2</td>
<td>3.1</td>
<td>6.4</td>
<td>3.5</td>
<td>6.7</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Criteria weights</td>
<td>0.2372</td>
<td>0.0518</td>
<td>0.1232</td>
<td>0.0323</td>
<td>0.4362</td>
<td>0.2010</td>
<td></td>
</tr>
</tbody>
</table>
In the next phase, the initial decision matrix needs to be normalized. Table 8 shows the normalized decision matrix.

**Table 8. Normalized decision matrix.**

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>$X_1^-$</th>
<th>$X_2^+$</th>
<th>$X_3^-$</th>
<th>$X_4^-$</th>
<th>$X_5^-$</th>
<th>$X_6^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>0.39215686</td>
<td>0.914285714</td>
<td>0</td>
<td>0.423076923</td>
<td>0.357142857</td>
<td>0.23076923</td>
</tr>
<tr>
<td>$A_2$</td>
<td>0.80392157</td>
<td>1</td>
<td>1</td>
<td>0.769230769</td>
<td>0.357142857</td>
<td>0.36538462</td>
</tr>
<tr>
<td>$A_3$</td>
<td>0.58823529</td>
<td>0.342857143</td>
<td>0.411764706</td>
<td>0.384615385</td>
<td>0.428571429</td>
<td>0.84615385</td>
</tr>
<tr>
<td>$A_4$</td>
<td>0</td>
<td>0</td>
<td>0.058823529</td>
<td>0.019230769</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$A_5$</td>
<td>0.37254902</td>
<td>0.171428571</td>
<td>0.647058824</td>
<td>0</td>
<td>0.25</td>
<td>0.42307692</td>
</tr>
<tr>
<td>$A_6$</td>
<td>0.56862745</td>
<td>0.314285714</td>
<td>0.382352941</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$A_7$</td>
<td>0.76470588</td>
<td>0.314285714</td>
<td>0.941176471</td>
<td>0.980769231</td>
<td>0.107142857</td>
<td>0.63461538</td>
</tr>
<tr>
<td>$A_8$</td>
<td>1</td>
<td>0.028571429</td>
<td>0.617647059</td>
<td>0.923076923</td>
<td>0.25</td>
<td>0.40384615</td>
</tr>
</tbody>
</table>

The sum of weighted comparability sequences ($S_i$), power-weighted comparability sequences ($P_i$), and evaluation score blueprints must be obtained after normalization. Table 9 shows the mentioned values.

**Table 9. Relative weight of alternatives.**

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>$S_i$</th>
<th>$P_i$</th>
<th>$k_{i1}$</th>
<th>$k_{i2}$</th>
<th>$k_{i3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>0.355922</td>
<td>4.228358</td>
<td>0.113803</td>
<td>56.06899</td>
<td>0.706765</td>
</tr>
<tr>
<td>$A_2$</td>
<td>0.586701</td>
<td>5.45201</td>
<td>0.149909</td>
<td>91.4931</td>
<td>0.930996</td>
</tr>
<tr>
<td>$A_3$</td>
<td>0.523312</td>
<td>5.375331</td>
<td>0.146432</td>
<td>81.92202</td>
<td>0.909402</td>
</tr>
<tr>
<td>$A_4$</td>
<td>0.006656</td>
<td>1.630695</td>
<td>0.040647</td>
<td>2</td>
<td>0.252433</td>
</tr>
<tr>
<td>$A_5$</td>
<td>0.331749</td>
<td>5.375331</td>
<td>0.146432</td>
<td>81.92202</td>
<td>0.909402</td>
</tr>
<tr>
<td>$A_6$</td>
<td>0.786921</td>
<td>5.699368</td>
<td>0.161012</td>
<td>121.727</td>
<td>1</td>
</tr>
<tr>
<td>$A_7$</td>
<td>0.466846</td>
<td>5.179685</td>
<td>0.140173</td>
<td>73.31828</td>
<td>0.870533</td>
</tr>
<tr>
<td>$A_8$</td>
<td>0.47403</td>
<td>5.118071</td>
<td>0.138822</td>
<td>74.35995</td>
<td>0.862142</td>
</tr>
</tbody>
</table>

The evaluation score blueprints were then normalized, and the maximum variance optimization model was constructed. Table 10 shows the normalized evaluation score blueprints of alternatives.

**Table 10. Normalized evaluation score blueprints of alternatives.**

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>$k_{i1}'$</th>
<th>$k_{i2}'$</th>
<th>$k_{i3}'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>0.113803</td>
<td>0.101348901</td>
<td>0.113803</td>
</tr>
<tr>
<td>$A_2$</td>
<td>0.149908702</td>
<td>0.165380645</td>
<td>0.149908702</td>
</tr>
<tr>
<td>$A_3$</td>
<td>0.146431541</td>
<td>0.14808019</td>
<td>0.146431541</td>
</tr>
<tr>
<td>$A_4$</td>
<td>0.040646602</td>
<td>0.00361515</td>
<td>0.040646602</td>
</tr>
<tr>
<td>$A_5$</td>
<td>0.109195768</td>
<td>0.094604906</td>
<td>0.109195768</td>
</tr>
<tr>
<td>$A_6$</td>
<td>0.161019633</td>
<td>0.220030734</td>
<td>0.161019633</td>
</tr>
<tr>
<td>$A_7$</td>
<td>0.140172977</td>
<td>0.132528293</td>
<td>0.140172977</td>
</tr>
<tr>
<td>$A_8$</td>
<td>0.138821777</td>
<td>0.134411181</td>
<td>0.138821777</td>
</tr>
</tbody>
</table>

For the next step, the maximum variance optimization model was constructed.

$$
\max \frac{1}{8} \sum_{i=1}^{8} \left(k_i' - \frac{1}{8}\right)^2
$$
By solving the above model, the final scores of each alternative were obtained. Table 11 shows the final scores and rankings of research alternatives.

Table 11. Final scores and rankings of alternatives.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Score</th>
<th>Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.1138</td>
<td>6</td>
</tr>
<tr>
<td>A2</td>
<td>0.1654</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>0.1481</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>0.0406</td>
<td>8</td>
</tr>
<tr>
<td>A5</td>
<td>0.1092</td>
<td>7</td>
</tr>
<tr>
<td>A6</td>
<td>0.22</td>
<td>1</td>
</tr>
<tr>
<td>A7</td>
<td>0.1402</td>
<td>4</td>
</tr>
<tr>
<td>A8</td>
<td>0.1388</td>
<td>5</td>
</tr>
</tbody>
</table>

Finally, by performing the MV–CoCoSo method, the natural hazards of Tehran city were ranked. The threat of earthquakes (A4) was found to be the most destructive natural hazard of this city. The threat of flooding (A5) was classified next, and the threat of landslides (A1) was recognized as the third natural hazard of Tehran. The threats of storms (A8), droughts (A7), dust events (A3), land subsidence (A2), and climate change (A6) were ranked next, respectively. It is noted that the MV–CoCoSo technique ranks the possible natural hazards of Tehran from the least dangerous (climate change) to the most dangerous (earthquakes).

The obtained results show the importance of investment and required planning to deal with the impacts of earthquakes, floods, and landslides as the three main threats to Tehran.

7. Sensitivity Analysis

In order to assess the robustness of the research methodology, two experiments were considered. First, experiment 1 has been designed to obtain criteria weights by utilizing another weighting method. Then, in experiment 2, three alternative assessment methods were used to verify the ranking obtained by MV–CoCoSo.

a. Experiment 1

The Best Worst method (BWM) is one of the MCDM weighting methods introduced by Rezaei in 2015 to assess criteria weights, which benefit from an optimization model to calculate the importance of each measure [69]. According to the BWM procedure, the best and the worst criteria must be determined before creating the pairwise matrix, which results in a more robust pairwise comparison. Six measures of this research have been evaluated using BWM to observe the discrepancy of criteria weights and their impact on the final rankings. Table 12 shows the criteria weight using BWM.
Table 12. Criteria weights using BWM.

<table>
<thead>
<tr>
<th></th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
<th>C₄</th>
<th>C₅</th>
<th>C₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights</td>
<td>0.2103</td>
<td>0.08575</td>
<td>0.103</td>
<td>0.03132</td>
<td>0.39821</td>
<td>0.17151</td>
</tr>
</tbody>
</table>

Furthermore, Figure 2 shows the comparison of ANP and BWM results.

Figure 2. BWM and ANP results comparison.

According to Figure 2, the differences between ANP and BWM results are negligible. Moreover, the weights obtained by BWM are tested using MV–CoCoSo to assess the effects and observe the possible ranking variation that arises from modifying the criteria weights. Figure 3 illustrates that only a slight change occurred after utilizing BWM, and the MV–CoCoSo prioritization is therefore considered robust.

Figure 3. ANP–MV–CoCoSo and BWM–MV–CoCoSo results.

b. Experiment 2

In this subsection, three recently developed MCDM techniques were utilized to assess the accuracy of MV–CoCoSo results: Evaluation based on Distance from Average Solution (EDAS) [70], Measurement Alternatives and Ranking according to Compromise Solution (MARCOS) [71], and Combined Compromise Solution (CoCoSo) [57] methods. These were
then chosen as the nominated techniques for experiment 2. Table 13 shows the implemented methods’ outcomes.

Table 13. Options prioritization using four MCDM methods.

<table>
<thead>
<tr>
<th></th>
<th>MV–CoCoSo</th>
<th>EDAS</th>
<th>CoCoSo</th>
<th>MARCOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>A5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>A6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>A7</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>A8</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Furthermore, Figure 4 compares obtained rankings using MV–CoCoSo, CoCoSo, EDAS, and MARCOS by considering the ANP outcomes.

The results of the comparison show that MV–CoCoSo results are robust. Across all techniques, Earthquake (A4), Flood (A5), and Landslide (A1) were found to be the top three destructive natural hazards of Tehran, respectively.

8. Managerial Implications

Tehran is the most populous city in Iran and the main center of political and economic management of the country, where critical infrastructure is located. Over the years, little attention has been paid to a plan to deal with possible natural hazards in Tehran. This research identified and prioritized potential natural hazards in Tehran using a new integrated MCDM method. It’s possible an earthquake crisis could paralyze the entire country if the government does not respond to the situation in Tehran. In order to deal with earthquakes, floods, and landslides, Tehran’s municipalities should develop strategies and organize construction programs to prepare for possible hazards. The second most likely natural hazard is flooding, which has also sounded the alarm of a crisis. Tehran’s streets

Figure 4. Comparison of four MCDM techniques’ outcomes.

The results of the comparison show that MV–CoCoSo results are robust. Across all techniques, Earthquake (A4), Flood (A5), and Landslide (A1) were found to be the top three destructive natural hazards of Tehran, respectively.

8. Managerial Implications

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...and sewage infrastructure cannot cope with floods, based on previous experiences. The third natural hazard that has challenged the city of Tehran is the landslide, which has also damaged parts of the city. It is advised that a map of high-risk zones be prepared, and the necessary preparations be made to strengthen those areas. The dust phenomenon is the next challenge, one that has profoundly impacted the city’s residents. By identifying its origin and making critical investments, we can reduce the severity of a natural hazard that could threaten citizens’ health.

9. Conclusions

Throughout history, many natural hazards have occurred in Tehran. By evaluating internal and external library sources, extracting the opinions of experts and specialists in the field, and examining the records of the occurrence of natural hazards in the city of Tehran, eight main threats were identified: floods, earthquakes, landslides, droughts, land subsidence, storms, climate changes, and dust phenomena. Next, six criteria were selected for ranking these threats, using library research and experts’ opinions. An analysis of the relationship between the criteria was then conducted using a questionnaire. After that, the pairwise comparison matrix of the measures was formed. Finally, the criteria’s weights were calculated using the ANP method. It was concluded that the consequences of natural hazards that demonstrate the greatest severity of damage and human casualties had the most significant priority, as more consequences indicate greater city vulnerability. As a result, such events reduce the availability of necessary urban services at the time of threat, severely disrupt the city’s stability, and result in a more significant crisis. The disaster severity scale is in the next rank because the intensity of the threat shows the scale of the occurrence of the disaster. The larger the threat occurrence, the more vulnerable the city is, and as a result, the city is forced to change its normal state and faces up to the challenges in managing the city. In the third rank is the possibility of a secondary threat. This index is essential regarding the likelihood that other perils, such as fire or security issues, will occur with a hazard. Therefore, this index shows other complications of the threat that can significantly expand the crisis level. The criterion of the city’s ability to recover is the next rank, with a slight difference; it indicates how long it will take for the crisis to subside and for the city to return to normal. The fifth rank is the index of responsibility or the existing crisis management situation, while the final rank is the history and frequency of threats. An essential point in examining these indicators is the relationship between these criteria. The ANP method was used to obtain more accurate results because this method can consider one-way and two-way relationships between the considered measures.

Following the weighting of the research measures, another survey was prepared, in which points were given to Tehran’s natural hazards based on each criterion. Then, by summarizing these questionnaires, the conclusion was reached that according to the Disaster severity scale in Tehran, the earthquake threat received the most points. Flooding ranked next, followed by landslides, climate changes, dust events, droughts, land subsidence, and storms. According to the responsive capacity criterion, the threat of land subsidence was ranked first, followed by landslides, earthquakes, dust events, climate changes, droughts, floods, and storms. In the context of the possibility of secondary threats, the three dangers of earthquake, flood, and landslide got the highest points, respectively. Based on the threat history evaluation, as expected, flood scored the highest, followed by an earthquake, and the threats of dust events, land subsidence, storm, drought, and climate change were ranked next, respectively. According to the Disaster consequence criterion, which was also the most meaningful criterion of our research, the earthquake threat got the highest point, followed by drought in the second rank, then flood in the third place. The following ranks thereafter were the hazards of storms, land subsidence, landslides, dust events, and climate change. Finally, according to the Recovery time and process index, the earthquake threat was ranked first, and then the hazards of landslides, land subsidence, storms, floods, drought, fine dust, and climate change, respectively.
Using the MV–CoCoSo technique, the natural hazards of Tehran were ranked, and the three main threats of Tehran were earthquakes, floods, and landslides, respectively. Furthermore, sensitivity analysis results showed that the research methodology was robust and appropriate to trust for the future planning of Tehran city.

Moreover, the complexity of the subject limits the measures and data that can be used to study the natural hazards of Tehran city. Besides data access, access to experts was also limited in the current study.

Future research could focus on utilizing fuzzy or grey theories to confront the subject’s ambiguity and complexity, along with considering environmental measures to evaluate the natural hazards.

Author Contributions: Conceptualization, M.B. and K.A.H.; Formal analysis, K.A.H. and S.H.Z.; Investigation, M.B. and S.H.Z.; Writing—original draft, M.B.; Writing—review & editing M.B. and S.H.Z.; Supervision, K.A.H.; Project administration, S.H.Z.; Funding acquisition, S.H.Z. All authors have read and agreed to the published version of the manuscript.

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