Future Earth and Environmental Science

Open Access Journal

March 2025| Volume 01 | Issue 01 | Pages 01-13

Journal homepage: https://fupubco.com/futech

https://doi.org/10.55670/fpll.fees.1.1.1

Future Publishing LLC

Article

Enhancing flood resilience: a comprehensive assessment of vulnerable centers through AHP-TOPSIS integration

Faraz Estelaji[1]*, Reihaneh Naseri[2], Alireza Naseri[3], Bita Rouhi Asl[4], Sahand Heidary[5]

[1]Department of Construction Engineering and Management, Faculty of Civil Engineering, Khajeh Nasir Toosi University, Tehran, Iran
[2]Department of Civil Engineering, Islamic Azad University, Tehran, Iran
[3]Department of Road and Transport Engineering, Faculty of Civil Engineering, Amirkabir University of Technology, Tehran, Iran
[4]Department of Environmental Management, Faculty of Marine Science and Technology, Azad University-North Tehran Branch, Tehran, Iran
[5]Faculty of Computer Engineering, Khajeh Nasir University, Tehran, Iran

ARTICLE INFO

Article history:
Received 05 December 2024
Received in revised form
11 January 2025
Accepted 20 January 2025

Keywords:
Risk assessment, Flood zoning,
AHP-TOPSIS Integration, Climate change,
Urban planning

*Corresponding author
Email address:
f.estelaji.27@gmail.com

DOI: 10.55670/fpll.fees.1.1.1

ABSTRACT

This paper addresses the examination of urban resilience to mitigate the life and financial impacts of natural disasters. One of the fundamental principles of urban resilience is the enhancement of infrastructure resilience during natural disasters and incidents. In this regard, a crucial step is improving the resilience of key urban centers. This research employs a combined method of the analytic Hierarchy Process (AHP) and TOPSIS to measure the resilience of flood-vulnerable buildings. Using a descriptive-analytical approach, the paper initially gathers the required data and information, identifies the influential criteria and sub-criteria for ranking the resilience of buildings against floods, calculates the final weights for each of the vulnerable city's key centers, and ranks the options using the TOPSIS method. The ranking results for the vulnerable centers in Hamedan city against floods indicate that, in order, the Industrial University with a weight of 1.000, Payam Noor University with 0.520, Amir Hotel with 0.297, Architecture and Art University with 0.273, and the Blood Transfusion Center with 0.153 are the key vulnerable buildings. The Blood Transfusion Center exhibits the lowest level of resilience, while the Industrial University shows the highest level of resilience. The method used in this research can be extended to all of the cities based on their unique decision-making criteria.

1. Introduction

Natural hazards within human habitation pose threats to life and can have far-reaching, irreparable effects on individuals and financial structures [1]. These occurrences, predating human history, have persisted from the inception of the Earth, subjecting it to various natural disasters such as floods, earthquakes, storms, and more. In contemporary times, crisis management has emerged as a valuable knowledge resource applied in urban management and planning to mitigate these natural disasters' human and financial impacts [2]. The vulnerability of key urban centers and their gravity in the face of natural disasters and accidents lead to inefficiencies, heightened public dissatisfaction, and a lack of service during emergencies [3]. Urban floods, exacerbated by climate change, the growth of urbanization, and constraints on urban infrastructure drainage, have imparted numerous adverse effects over recent decades [4]. Hence, investigating the vulnerability or resilience of these urban centers becomes a matter of critical importance. Identifying these key centers and assessing their vulnerability to various risks and threats is essential for making them more resilient [5]. The parameters, variables, criteria, or indicators selected for cities are contingent upon the specific effects anticipated for each architectural, sectoral, or social factor within a given region [6]. The organizational structure of these indicators is imperative [7]. Sequentially employing all indicators is crucial, as expert estimation may be necessary to compare simulation/model results with geographical data, facilitating the accurate determination of accident risks [8]. Recognizing the critical importance of investigating the vulnerability and resilience of urban buildings, particularly key structures facing natural disasters, researchers have dedicated significant efforts to this essential field [9]. A notable example is the work of Rus et al. [10], who focused on reducing the vulnerability of urban buildings to earthquakes by evaluating vulnerable urban areas. The study employed the Fuzzy AHP model and GIS software to craft earthquake scenarios of varying intensities. Specifically, the research targeted the 3rd district of Tehran Municipality. The results revealed varying levels of vulnerability, with districts 2, 3, 5, 4, 1, and 6 exhibiting the highest vulnerability based on the number of buildings.

In a distinct study titled "The development of categories: Different approaches in grounded theory", [11] researchers presented an innovative method exploring the nature of vulnerability. The evaluation extended beyond the mere assessment of vulnerability, incorporating economic evaluation, valuation, and accounting of the historical background of buildings. Furthermore, the study introduced fragility curves specific to historical buildings exposed to floods, enhancing our understanding of their susceptibility and aiding in formulating effective flood management strategies. These research endeavors underscore the multifaceted nature of urban building vulnerability, demonstrating the need for diverse approaches that consider both natural disaster scenarios and the unique characteristics of historic structures. Such investigations contribute significantly to the broader goal of creating resilient urban environments capable of withstanding and recovering from the impact of natural disasters.

Building upon the extensive research in urban vulnerability and resilience, various studies have taken diverse approaches to assess and enhance the resilience of urban areas in distinct contexts. In a study led by Zarrabi and colleagues, the team delved into the sensitive uses of Yasouj city, encompassing health centers, educational facilities, military installations, commercial hubs, as well as fire and rescue stations. Employing the analytical Hierarchy Process (AHP), entropy, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and S-HP models, the research aimed to comprehensively analyze the vulnerabilities and resilience levels of these crucial urban components [12].

Another study focused on the Darabkla watershed, where indicators and criteria for ecosystem services were prioritized. The research used entropy and TOPSIS multi-criteria decision-making techniques to identify key factors influencing ecosystem services in the watershed. This approach contributes to a holistic understanding of the environmental dynamics, aiding in the region's sustainable management of ecosystem services [13]. In a separate investigation, the resilience of an urban basin against floods was evaluated using the metric base cell network method. The research utilized the CADDIES model for flood simulation, identifying vulnerable basins and developing strategic measures to bolster the city's resilience against floods. This approach underscores the importance of tailored strategies based on local conditions, demonstrating the adaptability of methodologies to address specific challenges in urban flood resilience [14]. These studies collectively highlight the versatility and applicability of various models and decision-making techniques in assessing urban resilience, showcasing the need for context-specific approaches to comprehensively understand and enhance the capacity of urban areas to withstand and recover from adverse events [15]. An exploration of the research history, codes, standards, design guidelines, and evaluation plans reveals a limited number of existing operational indicators in the domain of urban resilience [16]. In practical applications, several indicators have been proposed to discern the value characteristics of resilience, broadly categorized into two groups [17]. The first category encompasses result-based indicators that evaluate persistence, resistance, and strength [18]. These indicators gauge the effectiveness of actions and policies implemented in response to challenges. The second category focuses on process-based indicators, evaluating compatibility, responsiveness, and irretrievability. These indicators monitor the progress of implementation strategies [19]. However, certain critical characteristics essential for comprehensive resilience assessments, such as redundancy, variety, connection, and cascading effects, are often overlooked in existing practices. To address this gap, the current research adopts a forward-thinking approach by incorporating the main dimensions of resilient systems and buildings identified by participants in the RAMSES workshop as indicators. By utilizing the insights gleaned from this collaborative workshop, the research employs resilience measures and metrics to provide a more holistic understanding of urban resilience [20]. This inclusive approach ensures that the assessment framework considers a broader spectrum of characteristics, contributing to a more nuanced and comprehensive evaluation of urban systems and buildings in the face of various challenges [21]. The incorporation of these dimensions not only enriches the understanding of resilience but also enables the development of targeted strategies to enhance urban systems' adaptive capacity and ability to recover from disruptions [22].

Resilience is characterized as the capacity of a system (denoted as 'x') to predict, absorb, compromise, and swiftly recover from adverse events ('y') [23]. This multifaceted ability unfolds over distinct time stages: the system actively resists and absorbs stress during an event, subsequently undergoing a recovery phase. These capabilities are contingent upon the adaptability to predict, prevent, and prepare the system before the occurrence of the event. In the realm of multi-indicator decision-making, the utilization of combined methods has become widespread and crucial in contemporary research. This approach is increasingly prevalent in articles and theses due to the limitations inherent in individual methods. To illustrate this, consider a multi-criteria decision-making (MCDM) problem with seven criteria and five options. Solving this problem exclusively with the Analytic Hierarchy Process (AHP) necessitates a 7x7 matrix and seven 5x5 matrices, resulting in a daunting 91 pairwise comparisons. This not only complicates the problem but also amplifies the computational load, potentially leading to expert reluctance in responding to the questionnaire.

To mitigate these challenges, a combined method is employed in this research, exemplified by integrating the TOPSIS method. In this scenario, the AHP method calculates the weights of the criteria, while the TOPSIS method ranks the available options. This amalgamation significantly reduces the number of paired comparisons to 56, presenting a more manageable approach known as the combined AHP-TOPSIS method. This study seeks to identify resilience indicators and subsequently rank them using the AHP-TOPSIS technique. This methodology aims to provide a comprehensive and efficient approach to resilience assessment, addressing the complexity of multi-criteria decision-making while ensuring practicality and expert engagement in the evaluation process.

2. Methodology

As dynamic entities, cities are perpetually exposed to internal and border-related risks. Urban resilience, therefore, hinges on the capability of the urban system to either protect itself or swiftly return to an optimal state. In this context, the resilience of urban buildings emerges as a crucial component of overall urban resilience [24]. The strategic implementation of passive defense serves as a resilience strategy to address patterns of vulnerability.

In the contemporary era, the convergence of complexities in urban life – encompassing natural hazards, technological crises, and social-security challenges – has contributed to a decline in urban resilience. Notably, the lack of resilience in key buildings is identified as a significant threat. Given that Hamedan city is situated on the slopes of Alvand Mountain, the runoff from this area traverses the city through several small and large rivers. These waterways, flowing through densely populated urban areas, present challenges in terms of organization and expansion. In the event of a flood, large sections of the city could be inundated, underscoring the critical need to assess the resilience of buildings located in high-risk zones.

2.1 Identification of important assets

The initial phase of this research involves the identification of crucial assets within the study area. Recognizing the significance of accurate asset identification, this step is foundational to subsequent analyses. The goal is to pinpoint assets that, if affected by floods, would pose a substantial threat to the essential functions and services of the area. The identification process relies on a comprehensive approach, incorporating insights from managers in various urban-related fields, reliable scientific sources, and past experiences.

2.2 River flow modeling using HecRAS software

The second stage of the research entails the use of HecRAS software for river flow modeling. HecRAS, a hydraulic modeling tool, is employed to simulate and analyze the behavior of rivers under different conditions. This stage aims to provide insights into the flow patterns of rivers within the study area, particularly focusing on potential flooding scenarios.

2.3 Adaptation of assets and modeling results of rivers in different return periods

This stage involves aligning the identified assets with the results obtained from river flow modeling conducted in various return periods. By doing so, the research aims to assess the vulnerability of important assets to potential flood events of different magnitudes. The adaptation process considers the dynamic nature of the rivers under varying conditions.

2.4 Determining building resilience components

In this stage, the research focuses on identifying and determining the components contributing to the resilience of key buildings against floods. A comprehensive assessment is conducted, considering factors such as structural integrity, emergency preparedness, and adaptive capacity. Understanding these components is crucial for developing effective strategies to enhance building resilience.

2.5 Ranking of resilience indicators of key buildings using the combined AHP-TOPSIS method

To establish a robust ranking system for resilience indicators, a combined Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) method is employed. This method considers multiple criteria in ranking resilience indicators for key buildings. The integration of AHP and TOPSIS enhances the decision-making process by providing a comprehensive and balanced assessment. This seven-stage research methodology is designed to comprehensively analyze and enhance the resilience of important buildings against floods. Each stage contributes valuable insights, contributing to informed decision-making and strategic planning for urban resilience in the study area.

2.6 Critical assets identification

The initial phase involves the recognition and prioritization of critical assets within the city—a fundamental step in this research. The subsequent analytical steps heavily rely on the precision with which the assets of Hamedan city are identified and prioritized during this stage. The primary objective of this phase is to discern assets that, in the event of damage or destruction, pose a substantial threat to the provisioning of information, communications, services, and resources essential for the city of Hamadan. To achieve this goal, a consolidated method has been employed, incorporating the perspectives of managers from diverse fields associated with urban affairs. This inclusive approach integrates the valuable insights of professionals, draws upon reliable scientific sources, and leverages existing experiences. The synthesis of opinions from multiple stakeholders, combined with robust scientific knowledge and practical experiences, enhances the accuracy and comprehensiveness of the asset identification and classification process for Hamedan City.

2.7 Integrated hydraulic modeling of flood-susceptible rivers using HecRAS

This research focuses on assets susceptible to flood threats, prompting an in-depth examination and analysis. This section delves into the study of rivers and their flow modeling. The primary objective of hydrological investigations is to ascertain the design flood for each river. To ensure a cohesive and comprehensive understanding of obtained floods, an integrated modeling approach is adopted, encompassing the entire catchment areas of both suburban and inner-city rivers. Achieving this entails the utilization of reliable software capable of solving equations for both permanent and non-permanent variable flows. Given the extensive operations involved and the critical nature of the information, the selection of appropriate software is of paramount importance. In this study, the Hec-RAS software was employed to model the hydraulics of rivers. This choice is made considering its capacity to determine hydraulic parameters along the river and at various stages, thereby ensuring the accuracy necessary for the successful execution of this research.

2.8 Adaptation of assets and hydraulic modeling of rivers

This phase employs overlapping functions to align assets with hydraulic modeling of rivers within the Geographic Information System (GIS), generating maps capable of addressing specific research inquiries. The selection of overlay methods depends on the type of data utilized and the purpose of the overlay. In this research, the feature overlay method is employed, introducing novel complexities that, while retaining the characteristics of previous complications, also incorporate additional features. This approach enhances the integration of asset data with hydraulic modeling outcomes, facilitating a more comprehensive analysis and visualization of the spatial relationships between assets and river dynamics.

2.9 Determining building resilience components

The Resilience Index, an evaluation method developed by Argonne National Laboratory, serves as a tool for comparing the resilience levels of critical infrastructures and strategically allocating limited resources for resilience improvement. This index relies on subjective evaluations from experts, focusing on three pivotal characteristics of resilience: "strength," "resourcefulness," and "recovery."

- **Strength:**

Definition: The capability to sustain critical operations and performance during a crisis.

Evaluation: Assesses the building's ability to maintain essential functions in the face of adversities.

- **Resourcefulness:**

Definition: The capability to prepare, respond, and manage a crisis or disturbance.

Evaluation: Examines the building's adeptness in anticipating, reacting to, and handling crises.

- **Recovery:**

Definition: The capability to swiftly and effectively return to or restore normal operations.

Evaluation: Measures the building's efficiency in recovering and restoring normalcy after a disruptive event [25].

The analysis of research findings commences with an examination of the subject and dimensions, as stipulated in the questionnaire developed by the researcher. Subsequently, the impacts of building resilience in floods on each dimension are quantified using Chi-Square analysis. Further, the influential factors contributing to building resilience in floods are identified through factor analysis. The subsequent step involves measuring the influence of building resilience in floods on each of the extracted factors. This comprehensive approach ensures a systematic exploration of the multifaceted components of building resilience in flood scenarios, providing valuable insights for further refinement and enhancement.

2.10 Ranking resilience indicators of key buildings using the combined AHP-TOPSIS method

This research employs the Analytic Hierarchy Process (AHP) to assess and rank the resilience of buildings in the face of flood-related challenges. The evaluation of building resilience necessitates the identification and analysis of numerous criteria and indicators. Consequently, the research identifies and specifies the criteria and sub-criteria influencing the ranking of buildings' resilience against floods. Considering the varying impact of these indicators, a pairwise comparison of these components is conducted through the AHP technique. This comparative analysis involves the solicitation of expert opinions from 50 experienced professionals in the fields of resilience and passive defense. Through this collaborative effort, the final weight of each criterion and sub-criterion is calculated, reflecting the collective expertise and insights of the participating experts. This structured approach, integrating AHP methodology, ensures a comprehensive and rigorous evaluation of the factors contributing to the resilience ranking of key buildings in flood-prone scenarios.

Moreover, it is noteworthy that the TOPSIS method, mentioned in the previous context, could also be employed in conjunction with AHP to refine the ranking process and provide a more robust evaluation framework.

2.11 Effective Criteria and Sub-Criteria in Resilience Rating

The criteria and sub-criteria for the leveling and assessment of assets have been systematically established in this research. Following the setup of a questionnaire and the subsequent distribution and collection of responses, the arithmetic mean of opinions from the sampled community has been calculated. This process is conducted through the incorporation of the Analytic Hierarchy Process (AHP) technique within the Expert Choice software, allowing for the determination of weighted criteria and sub-criteria relevant to the resilience rating of key city centers. These criteria and sub-criteria have been seamlessly adapted to align with the outcomes derived from an extensive study encompassing intra-urban and extra-urban hydrology, network hydraulics, and the modeling of rivers across different return periods. The integration of HEC-RAS software within the Geographic Information System (GIS) platform further enhances the adaptability and comprehensiveness of the resilience assessment. The AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods synergize in this context, contributing to the multi-criteria decision-making sub-index (MADM). AHP excels in both weighting criteria and ranking research options, while TOPSIS accommodates real numbers in decision matrices. The positive and negative criteria consideration in TOPSIS distinguishes between profit and cost aspects, aiding in the determination of the system's improvement. The technique is rooted in the concept that each selected factor should exhibit the smallest distance to the positive ideal factor (most important) and the largest distance to the negative ideal factor (least important), ensuring a comprehensive evaluation of factors contributing to resilience rating .The general algorithm of the TOPSIS method is based on the Figure 1 [26].

The TOPSIS method boasts several key advantages, contributing to its efficacy in decision-making and problem-solving scenarios:

Simultaneous consideration of quantitative and qualitative criteria: This method facilitates the simultaneous evaluation of both quantitative and qualitative criteria, providing a comprehensive assessment framework.

Handling a significant number of criteria: TOPSIS is well-suited for scenarios involving a substantial number of criteria, allowing for a thorough consideration of diverse factors in the decision-making process.

Simplicity and rapid application: The TOPSIS method is characterized by its simplicity and efficiency, enabling straightforward and swift application in decision-making contexts.

Dynamic response to input changes: The method allows for the alteration of input information, enabling the evaluation of the system's response to changes and adjustments.

Desirability of indicators: The TOPSIS method inherently considers the desirability of desired indicators, emphasizing the improvement or reduction in certain criteria based on problem-solving objectives.

Prioritization based on similarity to ideal solution: Prioritization in TOPSIS is executed by assessing the similarity of selected options to the ideal solution, taking into account the shortest distance from the ideal and the farthest distance from the worst solution.

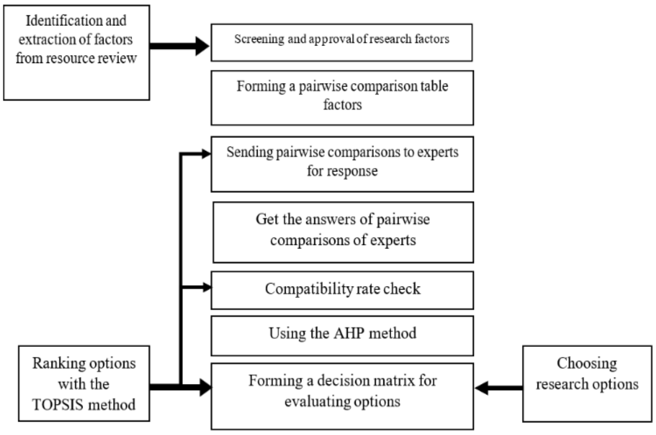

Figure 1. The general algorithm of TOPSIS method

Handling criteria of different types: Particularly advantageous when dealing with a mix of cost-type and profit-type criteria, TOPSIS easily identifies the ideal solution that optimally combines the best attainable values for all criteria.
Consideration of proximity to optimal solution: TOPSIS considers not only the distance to the worst solution but also the proximity to the optimal solution, providing a more nuanced assessment.
Quantitative output for prioritization: The method produces quantitative outputs, representing the priorities of options. These weights can be utilized in solving linear or integer programming problems as coefficients for the objective function, enhancing its practical applicability.

In this research, the Analytic Hierarchy Process (AHP) was employed to assess and rank the resilience of buildings against floods. Given that the ranking of buildings' resilience necessitates the identification and analysis of various criteria and indicators, the research specified the criteria and sub-criteria influencing the ranking of buildings' resilience against floods. To account for these indicators' varying degrees of influence, the AHP technique involved a pairwise comparison of these components, conducted by 50 experienced experts in the field of resilience and passive defense issues. The final weight of each criterion and sub-criterion was then calculated based on expert opinions. Experts and researchers have outlined steps for implementing AHP, and although the nature and manner of implementation may vary, the basic steps remain consistent. Here is an example:

2.12 Applying the AHP model: four major steps

Modeling: Identify the problem and the decision-making purpose in a hierarchy of decision elements, including decision indicators and decision options.
Preferential judgment: Conduct pairwise comparisons between different decision options based on each index. Assign relative importance to decision indices.
Calculating relative weights: Determine the weight and importance of decision elements relative to each other through numerical calculations.
Integration of relative weights: Combine relative weights to rank the decision options.
Hierarchical process implementation: Six main steps
Forming a hierarchical tree: Develop a hierarchical structure representing decision elements, criteria, sub-criteria, and alternatives.
Determining criteria, sub-Criteria, and alternatives: Clearly define the elements within the hierarchical structure.
Collecting data: Gather relevant data associated with each element.
Calculating data: Perform calculations to determine the relative importance of elements.
Analyzing sensitivity and inconsistency rate: Assess the sensitivity of the model to changes and evaluate the consistency of expert judgments.
Pairwise comparison: Record the comparison of weights in a matrix, assigning values based on the preference of one element over another. A scale from one to nine is commonly used for valuation, where higher values indicate greater importance and preference. These steps collectively contribute to a structured and systematic application of the AHP model, ensuring a comprehensive evaluation of the resilience of buildings against floods. Indeed, the AHP method relies on pairwise comparisons where the values assigned in the comparison matrix reflect the preference or importance of one element over another. In this context, a value of nine indicates the highest preference or importance, while a value of one signifies equal priority or importance. It's crucial to note that the paired comparison matrix is an inverse matrix. This means that if the comparative value of the row element "a" compared to the column element "b" is equal to nine, the comparative value of the row element "b" compared to the column element "a" will be equal to 1/9 (approximately 0.1111). To provide further clarity, if the preference of element "a" over "b" is strong (indicated by a high value like nine), the preference of "b" over "a" is considered weak. This reciprocal relationship ensures consistency in the matrix and aligns with the principle that if one element is more preferred than another, the reverse is less true. In quantitative terms, these judgments are often converted into numerical values between one and nine (Table 1). This conversion facilitates mathematical operations and the subsequent calculation of relative weights for decision elements, contributing to the overall AHP [27].

Table1. Preference value for pairwise comparisons

Preferences (verbal judgment)	Numerical value
Extremely Preferred	**9**
Very Strongly Preferred	**7**
Strongly Preferred	**5**
Moderately Preferred	**3**
Equally Preferred	**1**

Hamedan Province, encompassing an area of approximately 19,546 square kilometers, is situated as one of the mountainous regions within the western part of the country. The geographical coordinates place the province between 33 degrees 33 minutes to 35 degrees 38 minutes' north latitude and 47 degrees 45 minutes to 49 degrees 36 minutes east longitude. The provincial capital, Hamedan city, holds the distinction of being the most populous city and is positioned at an elevation of 1,870 meters above sea level [28]. Data from the synoptic station in Hamedan city provides insights into the climate characteristics. The highest average annual temperature recorded was 21.8 degrees Celsius in 2014, while the lowest reached 3.3 degrees Celsius in 2013. Notably, the highest average annual maximum temperature, at 40 degrees Celsius, occurred in 2015, with the lowest average minimum temperature recorded at -32.8 degrees Celsius in the same year. Over a 10-year period, the autumn season receives the highest average rainfall (88.55 mm), followed by spring and winter with 84.43 mm and 68.06 mm, respectively. In contrast, the summer season is identified as the driest period, experiencing an average of 44.7 mm of rainfall. Hamedan exhibits primarily mild slopes, with most areas falling within the range of zero to two degrees, which is considered acceptable from a defensive standpoint. However, locations with a zero-degree slope may face challenges related to rainwater collection and insufficient drainage to streams, leading to road flooding. Mitigation measures, such as creating a gentle slope, should be considered in these areas. The topographical features of Hamedan are influenced by the imposing Alvand Mountains, with the city nestled on the eastern side of these mountains. Alvand surrounds the city to the west, southwest, and south, imparting a picturesque quality akin to a jewel. Given the climatic conditions and topographical features, the Hamedan Crisis Management Organization is advised to remain vigilant. Collaborative efforts with other urban entities are essential to implementing flood warning systems, constructing structures exceeding flood levels, allocating resources for flood management, safeguarding wetlands, and promoting the planting of vegetation. Measures such as restoring rivers to their natural state and dredging riverbeds should be considered to control floods effectively. Additionally, attention should be given to areas with potential rainwater accumulation due to minimal slopes, necessitating tailored measures for gentle slope management. The unique position of Hamedan, surrounded by the Alvand Mountains, requires a strategic approach to crisis management and environmental protection. The geographical location of Hamedan city and the Map of the layers of assets of Hamadan city and the city's rivers are shown in Figures 2 and Figure 3.

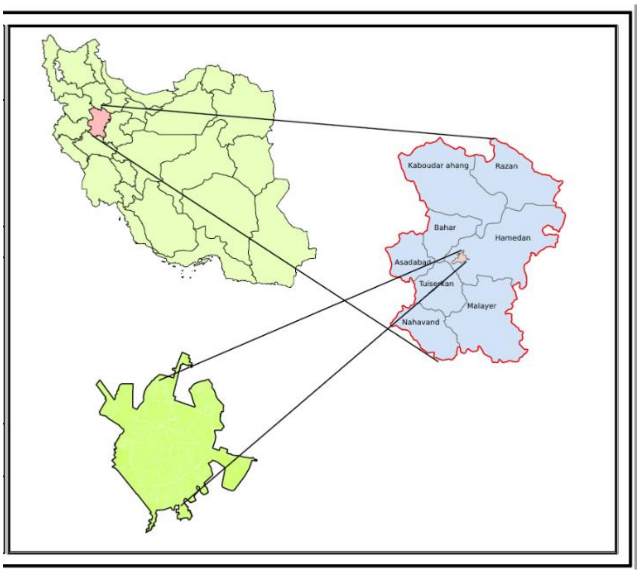

Figure 2. Geographical location of Hamedan city

To determine the amount of CN runoff curve in Hamedan city, city level zoning maps and land use maps of Hamedan city using GIS techniques combined and the number of levels of each use in each area, was calculated. Then, with the help of the standard table of CN values, a CN was assigned to each of the uses and the weighted average CN was calculated in each area. For the selection of each user's CN, the hydrological group of the soil is considered equal to B based on the contents of the hydrological report of the suburban areas. Zoning of the runoff curve number (CN) in Hamedan city and the watersheds adjacent to it is shown in Figure 4.

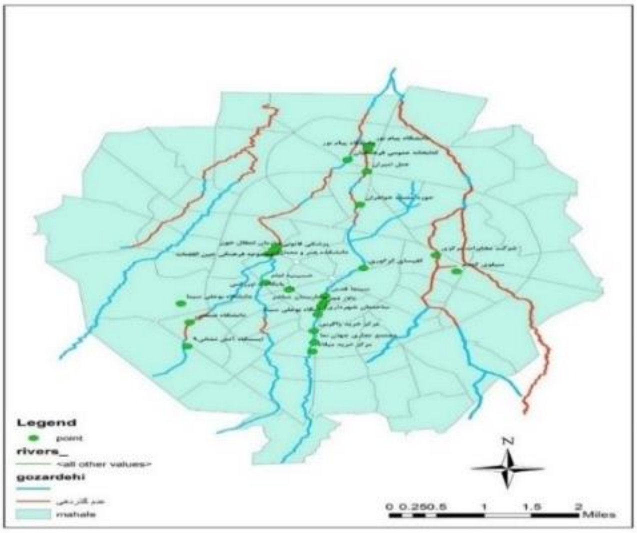

Figure 3. Map of the layers of assets of Hamadan city and the city's rivers

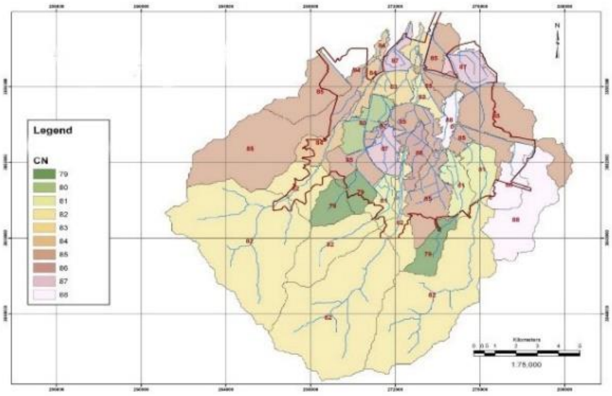

Figure 4. Zoning of the runoff curve number (CN) in Hamedan city and the watersheds adjacent to it

2.13 Mean vector of inconsistency

Considering that the pairwise comparison matrix is known and the priority vector is calculated, the unknown of this relationship is the vector of the highest eigenvalues that is calculated at this stage. On the other hand, the final maxλ is calculated by averaging the following vector values.

$$\max = \frac{1}{N}\sum_{i=1}^{n}\frac{aw}{w}\lambda \qquad (1)$$

maxλ: average vector of inconsistency
a: geometric mean of matrix ij (one horizontal plane)
wij: weight or priority of alternative I,j (a horizontal level)
N: number of alternatives compared

maxλ is always greater than or equal to n, and if the matrix deviates from the compatible state, maxλ will deviate from n.

This difference of maxλ and n can be a good measure to measure the incompatibility of the matrix [28, 29].

$$\mathrm{I.I} = \frac{\sum \lambda \max - \mathrm{n}}{\mathrm{n}-1} \tag{2}$$

In the above relation, max λ is the element of the eigenvector and n is the number of criteria. The eigenvector element is obtained from the following relation: Equation (3) Criterion weight / Valuation matrix row × Weights column = maxλ they have calculated the values of the inconsistency index for the matrices whose numbers have been chosen completely randomly and called it the inconsistency index of the random matrix, Inconsistency index of the random matrix which is obtained according to Table 2.

The inconsistency rate serves as a crucial mechanism for evaluating the validity of respondents' responses in comparative matrices. These metric gauges the reliability of respondents' assessments when comparing sub-criteria with alternatives. The calculation of the inconsistency rate involves six essential steps, which encompass the weighted set vector, inconsistency vector, average inconsistency vector, inconsistency index, random inconsistency index, and, ultimately, the inconsistency rate. To streamline the process and enhance efficiency, the calculations related to the weighted set vector, inconsistency vector, and average inconsistency vector are consolidated into a single operation [30].

The six steps for computing the incompatibility rate are outlined below:

- **Weighted set vector:** Compute the weighted set vector, capturing the weighted contributions of each element.
- **Inconsistency vector:** Determine the inconsistency vector, illustrating inconsistencies in respondents' evaluations.
- **Average inconsistency vector:** Calculate the average inconsistency vector, consolidating inconsistencies across matrices.
- **Inconsistency index:** Derive the inconsistency index, quantifying the overall level of inconsistency.
- **Random inconsistency index:** Establish the random inconsistency index, serving as a baseline for comparison.
- **Inconsistency rate:** Assess the inconsistency rate by dividing the inconsistency index by the random inconsistency index for the corresponding matrix dimension.

This calculated inconsistency rate provides a valuable criterion for evaluating the level of inconsistency in respondents' assessments. A lower inconsistency rate signifies higher reliability and consistency in responses to comparative matrices, contributing to the overall robustness of the analysis. For each matrix, a suitable criterion for assessing inconsistency is obtained by dividing the inconsistency index by the inconsistency index of a random matrix with the same dimension. This derived ratio is termed the inconsistency rate. The inconsistency rate serves as a key indicator for evaluating the level of inconsistency in respondents' assessments within a specific matrix.

Table 2. Inconsistency index of the random matrix

Criterion number	1	2	3	4	5	6	7	8	9	10
I.I.R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.45

A lower inconsistency rate indicates a higher degree of reliability and consistency in the responses to comparative matrices, thereby enhancing the credibility of the analytical results [31].

$$\mathrm{IR} = \frac{\mathrm{I.I}}{\mathrm{I.I.R}} \tag{3}$$

The determination of an acceptable level of inconsistency for a matrix or system is subjective and contingent upon the decision maker's preferences. This predefined threshold provides a practical guideline for decision makers to assess the reliability of the obtained results and prompts a reconsideration of judgments if the inconsistency exceeds the suggested limit. The 0.1 threshold serves as a practical benchmark to ensure the robustness and coherence of the decision-making process. After determining the criteria weights, it is imperative to utilize a ranking model for assessing the resilience of buildings against floods. In this study, the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) model is employed for this purpose.

The TOPSIS model, introduced by Yin et al. stands out as one of the premier multi-indicator decision-making models and is widely employed in various fields. In this method, akin to other Multiple Attribute Decision Making (MADM) approaches, m options are evaluated across n indicators. The fundamental principle underlying this technique is rooted in the concept that the selected option should exhibit the smallest distance to the positive ideal solution (representing the best possible state) and the greatest distance to the negative ideal solution (representing the worst possible state). The method assumes uniform desirability for each index, either increasing or decreasing. The application of the TOPSIS model enables a comprehensive evaluation of building resilience against floods, considering multiple criteria simultaneously. This method facilitates decision-making by providing a clear ranking of alternatives based on their overall performance in relation to the defined criteria. Quantification and de-scaling of the decision matrix (N) involve a crucial step known as norm de-scaling for scaling purposes [32].

- **Quantification:** Convert the raw data in the decision matrix (N) to a quantitative form. This step ensures that all criteria are measured on a standardized scale, allowing for meaningful comparisons.
- **De-Scaling with norm de-scaling:** The norm de-scaling technique is applied to bring the values in the decision matrix to a common scale. This process typically involves normalization, which is achieved by dividing each value by the Euclidean norm of its respective column. The Euclidean norm is calculated as the square root of the sum of the squares of the values in the column.

The application of norm de-scaling ensures that all criteria are appropriately scaled and comparable, creating a normalized decision matrix that is conducive to further analysis, such as weighting and evaluation within the TOPSIS model. This step is vital for maintaining the integrity and accuracy of the decision-making process.

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=0}^{n} x_{ij}}} \tag{4}$$

Obtaining the weighted scale-free matrix (V) involves multiplying the scale-free matrix (N) by the diagonal matrix of weights ($\mathrm{W}_{\mathrm{mxn}}$).

- **Scale-free matrix (N):** The scale-free matrix, N, represents the normalized and de-scaled decision matrix.
- **Diagonal matrix of weights (W_{mxn}):** The diagonal matrix, W_{mxn}, contains the weights assigned to each criterion. The weights are distributed along the diagonal of the matrix.
- **Multiplication:** Multiply the scale-free matrix (N) by the diagonal matrix of weights (W_{mxn}). This is typically done element-wise, with each element in the resulting matrix representing the product of the corresponding elements in N and W.

Mathematically, the process can be expressed as follows:

$$V = N \times W_{m\times n} \tag{5}$$

The resulting matrix, V, represents the weighted scale-free matrix, incorporating the influence of the assigned weights on each criterion. This matrix is utilized in subsequent steps of the TOPSIS model for further analysis and decision-making. In the context of the TOPSIS model, the positive ideal solution (V_i^+) and negative ideal solution (V_i^-) are determined as follows:

Positive Ideal Solution(V_i^+): For each criterion (column) in the weighted scale-free matrix V, identify the maximum value among all alternatives. The positive ideal solution, V_i^+, is composed of the maximum values for each criterion.

Mathematically: $V_j^+ = \max\,(V_{1j}\,.V_{2j}\,.V_{3j}\,.\cdots.V_{mj})$

Negative Ideal Solution(V_j^-): Similarly, for each criterion (column) in the weighted scale-free matrix V, identify the minimum value among all alternatives. The negative ideal solution, V_i^-, is composed of the minimum values for each criterion.

Mathematically: $V_j^- = \min\,(V_{1j}\,.V_{2j}\,.V_{3j}.\cdots.V_{mj})$

These ideal solutions represent the extreme values for each criterion, with the positive ideal solution reflecting the most desirable state (maximizing criteria), and the negative ideal solution representing the least desirable state (minimizing criteria). The determination of these ideal solutions is a crucial step in the TOPSIS model for subsequent distance calculations and ranking of alternatives. In the TOPSIS model, obtaining the distance of each option to the positive and negative ideal involves calculating the Euclidean distance for each alternative. The Euclidean distance (d_i^+ and d_i^-) is determined based on the ideal solutions:

Best Value (Positive Ideal Solution): For positive indicators, the best value is the largest. For negative indicators, the best value is the smallest.

Worst Value (Negative Ideal Solution): For positive indicators, the worst value is the smallest. For negative indicators, the worst value is the largest. The Euclidean distance for each option (alternative) 'i' is calculated using the following formula:

$$d_j^+ = \sqrt{\textstyle\sum_{k=1}^{n}\left(V_{ik} - V_j^+\right)^2} \qquad i=1,2,\ldots,n \tag{6}$$

$$d_j^+ = \sqrt{\textstyle\sum_{k=1}^{n}\left(V_{ik} - V_j^-\right)^2} \qquad i=1,2,\ldots,n \tag{7}$$

Where:

V_{ik} Represents the value of alternative 'i' for criterion 'k'.
V_j^+Represents the positive ideal solution for criterion 'j'.
V_j^- Represents the negative ideal solution for criterion 'j'.

These distances represent the proximity of each alternative to the positive and negative ideal solutions, respectively. A smaller distance to the positive ideal and a larger distance to the negative ideal indicate a more favorable ranking for an alternative. The calculation of these distances is fundamental for the subsequent ranking of alternatives in the TOPSIS model. Indeed, TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) belongs to the compensatory group of decision-making methods. It operates on the principle that the selected option should have the smallest distance from the positive ideal solution and the largest distance from the negative ideal solution. This concept is fundamental to the methodology of TOPSIS and plays a crucial role in the ranking of alternatives. Key characteristics of TOPSIS include:

- **Uniform increasing and decreasing trend:** TOPSIS assumes a uniform increasing trend for positive indicators and a uniform decreasing trend for negative indicators. This means that for positive indicators, a larger value is more desirable, while for negative indicators, a smaller value is preferable. This uniform trend simplifies the determination of positive and negative ideal points.
- **Distance-based ranking:** The method determines the Euclidean distance of each alternative from both the positive and negative ideal solutions. The ranking is then based on the proximity of alternatives to these ideal solutions.
- **Compensatory nature:** Being a compensatory method means that strengths in certain criteria can compensate for weaknesses in others. TOPSIS considers the overall performance of alternatives across all criteria.

By considering both positive and negative indicators and utilizing the concept of Euclidean distances, TOPSIS provides a comprehensive and systematic approach to decision-making, particularly in situations where multiple criteria influence the evaluation of alternatives. The relative closeness (CL) of an option to the ideal solution in the TOPSIS method is determined using the following equation:

$$CL_i = \frac{d_j^-}{d_j^- + d_j^+} \tag{8}$$

Where:
CL_iRepresents the relative closeness of option 'i' to the ideal solution.
d_j^-Is the Euclidean distance of option 'i' to the negative ideal solution.
d_j^+Is the Euclidean distance of option 'i' to the positive ideal solution.

The relative closeness ranges between 0 and 1, with higher values indicating greater proximity to the ideal solution. A value closer to 1 suggests a better ranking for the option. The calculation of relative closeness is a key step in determining the final ranking of alternatives in the TOPSIS method.

3. Results and discussion

In this study, the identified key centers of the city include the Blood Transfusion Center, University of Technology, University of Architecture and Art, Payam Noor University, and Amiran Hotel. The inconsistency, as determined by Expert Choice11 software, was found to be 0.06, indicating an acceptable level in pairwise comparisons of criteria. As presented in Table 3, the balance redundancy indices, with cascading potential effects (weight: 0.077), along with performance capacity (weight: 0.056), and the replacement index of systems and factors (weight: 0.054), exhibit the highest weights.

Table 3. Weighting the indicators

Rows	resilience components	sub-resilience components	weights
1	Adaptability - flexibility	Change while maintaining or improving performance	0.049
		evolution	0.045
		Rapid adoption of alternative strategies	0.05
		Timely response to changing conditions	0.027
		Open design and flexible structures	0.049
2	Connection – Feedback – Safety – Failure	shock absorption	0.007
		Absorb the cumulative effects of slow-onset challenges	0.012
		Avoid catastrophic failure if the threshold is exceeded	0.007
		Gradual rather than sudden failure	0.013
		failure without cascading effects (domino effect)	0.024
		Pairwise analysis of human-technology system	0.005
		Identify the blocking effects and possible compromises with reduction	0.014
		Identifying synergies with other city policies, estimating added value	0.015
3	Dependence on local ecosystems	Flood control	0.012
		Bio-climatic design and management	0.006
4	Variety	Spatial diversity – key assets and functions that are physically distributed and not all affected by a specific event at any time.	0.0146
		Functional diversity - multiple ways of dealing with a particular need	0.021
		Equilibrium diversity with potential cascading effects	0.013
5	Learning-Memory-Prediction	Learning from past experiences and failures	0.003
		Use information and experience to create new adaptations	0.003
		Avoid repeating past mistakes	0.005
		Collect, store, and share experience	0.009
		Construction based on long-term value and history of the city	0.007
		Integrating resilience into long-term development scenarios	0.02
6	Function	Performance capacity	0.056
		System quality in a suitable and efficient way	0.013
		Self-sufficiency - reducing external dependence	0.019
		It performs better than other buildings	0.039
7	Response speed	In taking casualties, including death and illness	0.007
		reorganization	0.015
		Maintaining performance and re-establishing it	0.032
		Restore the structure	0.017
		Establishing public order	0.013
		Prevent future disruption	0.005
8	Redundancy - segmentation	Replacement of systems, agents of systems	0.054
		Buffer from external shocks or changes in demand	0.013
		Replacing components with modular parts	0.026
		Balance redundancy with potential cascading effects	0.077
9	resourcefulness	Identifying and predicting problems	0.013
		Prioritize	0.011
		Mobilizing the resources of visualization, planning, cooperation and action	0.014
		re-evaluation	0.006
		Integrating resilience into work and administration processes	0.052
		Getting cooperation from citizens	0.03
10	Strength	Resistance to a level of stress	0.003
		Without degradation and loss of performance	0.015
		Capacities that guarantee adequate margins	0.006

On the other hand, learning indices from experiences, past failures, and the use of information and experience to create new adaptation and resistance to stress, with a weight of 0.003, have the lowest weight in the assessment of building resilience against floods. These findings highlight the significance of certain criteria in determining the resilience of buildings, providing valuable insights into the factors contributing most significantly to the resilience rating. The identified key centers play a crucial role in the overall assessment and planning for flood resilience in the city. After establishing the importance of the criteria weights, the TOPSIS model was employed to determine the resilience ranking of buildings against floods.

Based on the positive and negative ideal Table 4 (Appendix) , the criterion with the highest positive ideal value is the surplus balance index with cascading potential effects, having a value of 0.257. Conversely, the criterion with the lowest negative ideal value is the resistance index to a level of stress, with a value of 0.002. These values indicate the extremes in desirability for positive and negative indicators, respectively, within the criteria considered for assessing building resilience against floods. As Table 5 shows, the University of Technology has the smallest distance from the positive ideal and the largest distance from the negative ideal. Determining the relative closeness (CL) of an alternative to the ideal solution:

As illustrated in the ranking Table 6, the University of Technology building, with a CL (Closeness) value of one, emerges as the most resilient building in the study. Following closely, the Payam Noor University building secures the second position, while the Amiran Hotel building claims the third spot. The University of Architecture and Art building attains the fourth position, and the Blood Transfusion Center building, with a CL value of 0.153, occupies the fifth rank. Notably, the building of the Blood Transfusion Center exhibits the lowest level of resilience among the five buildings under investigation. These findings provide a comprehensive understanding of the relative resilience levels of the studied buildings against floods.

Table 5. Distance from positive and negative ideal of buildings

Option	Distance from ideal positive d+	Distance from ideal negative d-
blood transition	0.424	0.000
industrial University	0.000	0.239
University of Architecture and Art	0.324	0.122
Payam Noor university	0.147	0.160
Amiran Hotel	0.262	0.110

Table 6. The final ranking of building resilience

Option	Final value of the rating	Rating of buildings
blood transition	0.153	5
industrial University	1.000	1
University of Architecture and Art	0.273	4
Payam Noor university	0.520	2
Amiran Hotel	0.297	3

4. Conclusion

The enhancement of infrastructure resilience in the face of natural disasters is a fundamental principle in the pursuit of resilient cities. In alignment with this principle, a critical step is the assessment of resilience in key urban centers. This research employs a comprehensive approach, combining the Analytical Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), to evaluate the resilience of buildings susceptible to floods. Measuring the resilience of buildings necessitates the meticulous identification and analysis of various criteria and indicators. Consequently, this research specifies the criteria and sub-criteria crucial in determining the resilience ranking of buildings against floods. Through the AHP technique, experienced experts in the fields of resilience and passive defense conducted a pairwise comparison of these components, leading to the calculation of their final weights. The results highlighted the varying influence of indicators, with balance redundancy indicators, performance capacity, and the replacement index of systems or factors holding the highest weights. On the other hand, learning indicators from experiences and failures, along with the use of information and experience to foster adaptation and resistance to stress, exhibited the lowest weights. Subsequent to the AHP analysis, the TOPSIS method was applied to rank the options based on their resilience indicators. The University of Technology emerged as the most resilient building, closely followed by Payam Noor University and Amiran Hotel. The University of Architecture and Art secured the fourth position, while the Blood Transfusion Center exhibited the lowest level of resilience among the key buildings. In conclusion, this research contributes valuable insights into the resilience levels of key buildings in the face of floods. The findings provide a robust foundation for informed decision-making and strategic planning to enhance the overall resilience of urban centers, aligning with the principles of building resilient cities. The research findings reveal crucial insights into the factors influencing the resilience of buildings vulnerable to flooding in Hamedan city. The weight analysis resulting from the AHP method demonstrates the varying importance of different indicators. Specifically, the balance redundancy indicators with cascading potential effects, boasting a weight of 0.077, along with performance capacity with a weight of 0.056, and the replacement index of systems or factors of systems with a weight of 0.054, emerge as the most influential in determining building resilience. Contrastingly, indicators related to learning from past experiences and failures, and the utilization of information and experience to facilitate new adaptation and resistance to stress, carry a lower weight of 0.003. This suggests that these particular aspects contribute less significantly to the overall determination of building resilience against floods. Subsequent to the AHP analysis, the TOPSIS method was applied to rank the options based on their resilience indicators. The outcomes provide a clear hierarchy of resilience levels among key buildings in Hamedan city vulnerable to flooding. The University of Technology secures the top position, demonstrating the smallest distance from the positive ideal and the largest distance from the negative ideal. Following closely are Payam Noor University, Amiran Hotel, University of Architecture and Art, and the Blood Transfusion Center, with varying degrees of resilience. In essence, this research not only identifies the critical factors influencing building resilience but also establishes a ranking system that aids in prioritizing strategic interventions. These insights are invaluable for urban planners, policymakers, and stakeholders, facilitating informed decisions aimed at enhancing the overall resilience of key buildings in the face of potential flood threats in Hamedan city. The results of the research, employing the TOPSIS method to rank the key centers of Hamedan city against flooding, reveal a clear hierarchy of resilience levels among the identified buildings. The University of Technology emerges as the most resilient, characterized by the smallest distance from the positive ideal and the largest distance from the negative ideal. The ranking of key centers in Hamedan city, in terms of resilience against flooding, is as follows:

- University of Technology
- Payam Noor University
- Amiran Hotel
- University of Architecture and Art
- Blood Transfusion Center

Notably, the Blood Transfusion Center is identified as having the lowest level of resilience among the key centers, while the University of Technology stands out with the highest level of resilience. This ranking provides valuable insights for decision-makers and urban planners, offering a strategic framework for prioritizing interventions and enhancing the overall resilience of these key buildings in the face of potential flood threats in Hamedan city. In the supplementary and confirmatory studies of this research, further investigations can be conducted to enhance the understanding of building resilience against floods. Chi-square analysis can be employed to measure the effects of building resilience in floods on each dimension. This statistical method can help assess the significance and relationships between different dimensions of building resilience. Additionally, factor analysis can be utilized to identify the effective factors contributing to building resilience in floods. This technique enables the extraction of underlying factors that influence resilience, providing a more nuanced understanding of the key elements involved. Furthermore, it is recommended to explore and measure the impact of building resilience in floods on each of the identified factors. This in-depth analysis can offer valuable insights into the specific contributions of resilience components and guide targeted strategies for improving overall building resilience against flood events.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

Datasets analyzed during the current study are available and can be given following a reasonable request from the corresponding author.

Conflict of interest

The authors declare no potential conflict of interest.

References

[1] Whitmee, S., et al., Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. The lancet, 2015. 386(10007): p. 1973-2028.

[2] Bankoff, G., Time is of the Essence: Disasters, Vulnerability and History1. International Journal of Mass Emergencies & Disasters, 2004. 22(3): p. 23-42.

[3] Estelaji, F., A. Naseri, and R. Zahedi, Evaluation of the Performance of Vital Services in Urban Crisis Management. Advances in Environmental and Engineering Research, 2022. 3(4): p. 1-19.

[4] Zahedi, R., et al., Potentiometry of wind, solar and geothermal energy resources and their future perspectives in Iran. Environment, Development and Sustainability, 2024: p. 1-27.

[5] Estelaji, F., et al., Potential measurement and spatial priorities determination for gas station construction using WLC and GIS. Future Technology, 2023. 2(4): p. 24-32.

[6] Javanroodi, K., et al., Designing climate resilient energy systems in complex urban areas considering urban morphology: A technical review. Advances in Applied Energy, 2023: p. 100155.

[7] Zahedi, R., et al., Numerical analysis of water, energy, and environment nexus in the hybrid thermal and solar multigeneration power plants. Energy Science & Engineering, 2024.

[8] Moraci, F., et al., Cities under pressure: Strategies and tools to face climate change and pandemic. Sustainability, 2020. 12(18): p. 7743.

[9] Naseri, A., et al., Simulating the performance of HOV lanes for optimal urban traffic management. Transportation Research Interdisciplinary Perspectives, 2024. 23: p. 101010.

[10] Rus, K., V. Kilar, and D. Koren, Resilience assessment of complex urban systems to natural disasters: A new literature review. International journal of disaster risk reduction, 2018. 31: p. 311-330.

[11] Kelle, U., The development of categories: Different approaches in grounded theory. The Sage handbook of grounded theory, 2007: p. 191-213.

[12] ASL, J.A., A. Zarrabi, and M. Taghvaei, An Analysis of Iranian Electronic Cities Case Study: Uremia City (Challenges and Opportunities). Editorial Team: p. 123.

[13] Estelaji, F., A. Abasi Semnani, and E. Alipouri, Flooding of Lorestan region with stamp strategies led by crisis management. Journal of Range and Watershed Managment, 2021. 74(1): p. 1-11.

[14] Estelaji, F., et al., Earthquake, flood and resilience management through spatial planning, decision and information system. Future Technology, 2024. 3(2): p. 11-21.

[15] Saqlain, M., Sustainable hydrogen production: A decision-making approach using VIKOR and intuitionistic hypersoft sets. Journal of Intelligent Management Decision, 2023. 2(3): p. 130-138.

[16] Bouchama, F. and M. Kamal, Enhancing Cyber Threat Detection through Machine Learning-Based Behavioral Modeling of Network Traffic Patterns. International Journal of Business Intelligence and Big Data Analytics, 2021. 4(9): p. 1-9.

[17] Mahmoudi, N., et al., Environmental sustainability in hospitals: Dual analysis of electrical consumption and pollutant emissions. Cleaner Engineering and Technology, 2024: p. 100740.

[18] Tayefeh, A., et al., Advanced bibliometric analysis on water, energy, food, and environmental nexus (WEFEN). Environmental Science and Pollution Research, 2023: p. 1-20.

[19] Cimellaro, G.P., et al., PEOPLES: a framework for evaluating resilience. Journal of Structural Engineering, 2016. 142(10): p. 04016063.

[20] Linkov, I. and B.D. Trump, The science and practice of resilience. 2019: Springer.

[21] Shaghaghi, A., et al., Proposing a new optimized forecasting model for the failure rate of power distribution network thermal equipment for

educational centers. Thermal Science and Engineering, 2023. 6(2): p. 2087.

[22] Nowell, B., C.P. Bodkin, and D. Bayoumi, Redundancy as a strategy in disaster response systems: A pathway to resilience or a recipe for disaster? Journal of Contingencies and Crisis Management, 2017. 25(3): p. 123-135.

[23] Zahedi, R., M.H. Ghodusinejad, and S. Gitifar, Threats Evaluation of Border Power Plants from the Perspective of Fuel Type and Providing Solutions to Deal with Them: A Case Study of Iran. Transactions of the Indian National Academy of Engineering, 2022: p. 1-13.

[24] Kerntopf, M., Thou Ought to Deborder: The Normative Influence of Regional IGOs on Intra-Communal Bordering in the Baltic Sea Region and the South China Sea Region. 2023.

[25] D'Agostino, D., et al., Assessment of passive and active buildings resilience to gas supply disruption in winter across European climates. Sustainable Cities and Society, 2023. 92: p. 104461.

[26] Štilić, A. and A. Puška, Integrating Multi-Criteria Decision-Making Methods with Sustainable Engineering: A Comprehensive Review of Current Practices. Eng, 2023. 4(2): p. 1536-1549.

[27] Fawzy, M.M., et al., Prioritization of Egyptian road maintenance using analytic hierarchy process. International Journal of Pavement Research and Technology, 2023: p. 1-14.

[28] Abdollahi, S., et al., Spatial assessment of biodiversity and conservation priorities in Hamedan Province, Iran, using a landscape ecology approach. Journal of Environmental Studies and Sciences, 2024: p. 1-14.

[29] Opper, M., O. Winther, and M.J. Jordan, Expectation consistent approximate inference. Journal of Machine Learning Research, 2005. 6(12).

[30] Feldman, Y. and O. Lobel, The incentives matrix: The comparative effectiveness of rewards, liabilities, duties, and protections for reporting illegality. Tex. L. Rev., 2009. 88: p. 1151.

[31] Peres-Neto, P.R., et al., Variation partitioning of species data matrices: estimation and comparison of fractions. Ecology, 2006. 87(10): p. 2614-2625.

[32] Yin, X., D. Chen, and J. Ji, How does environmental regulation influence green technological innovation? Moderating effect of green finance. Journal of Environmental Management, 2023. 342: p. 118112.

Appendix

Table 4. Positive and negative ideal

	Change while maintaining or improving performance	evolution	Rapid adoption of alternative strategies	Timely response to changing conditions	Open design and flexible structures	shock absorption	Absorb the cumulative effects of slow-onset challenges	Avoid catastrophic failure if the threshold is exceeded	Gradual rather than sudden failure	failure without cascading effects (domino effect)	Pairwise analysis of human-technology system	Identify the blocking effects and possible compromises with reduction
A+	0.1638	0.1165	0.2034	0.0699	0.1269	0.0234	0.0401	0.0236	0.0435	0.0809	0.0090	0.0369
A-	0.0410	0.0388	0.0407	0.0233	0.0423	0.0059	0.0100	0.0059	0.0109	0.0202	0.0045	0.0123
	Identifying synergies with other city policies, estimating added value	Flood control	Bio-climatic design and management	Spatial diversity – key assets and functions that are physically distributed and not all affected by a specific event at any time.	Functional diversity - multiple ways of dealing with a particular need	Equilibrium diversity with potential cascading effects	Learning from past experiences and failures	ˡUse information and experience to create new adaptations	Avoid repeating past mistakes	Collect, store, and share experience	Construction based on long-term value and history of the city	Integrating resilience into long-term development scenarios
A+	0.0270	0.0317	0.0108	0.0488	0.0691	0.0429	0.0079	0.0079	0.0132	0.0083	0.0065	0.0528
A-	0.0135	0.0106	0.0054	0.0122	0.0173	0.0107	0.0026	0.0026	0.0044	0.0083	0.0065	0.0176
	Performance capacity	System quality	Self-sufficiency - reducing external dependence	نSabbat works better than other buildings	In taking casualties, including death and illness	reorganization	Maintaining performance and restoring it	Restore the structure	بEstablishing public order	Prevent future disruption	Replacement of systems, agents of systems	Buffer from external shocks or changes in demands
A+	0.1865	0.0424	0.0620	0.1314	0.0279	0.0502	0.1045	0.0568	0.0431	0.0167	0.1776	0.0424
A-	0.0466	0.0106	0.0155	0.0328	0.0056	0.0125	0.0261	0.0142	0.0108	0.0042	0.0444	0.0106
	Replacing components with modular parts	Balance redundancy with potential cascading effects	Identifying and predicting problems	Prioritize	Resource mobilization, visualization, planning, cooperation and action	re-evaluation	Integrating resilience into work and administration processes	Getting cooperation from citizens	Resistance to a level of stress	Without degradation and loss of performance	Capacities that guarantee adequate margins	
A+	0.0855	**0.2575**	0.0343	0.0290	0.0252	0.0108	0.0937	0.0277	0.0122	0.0497	0.0154	
A-	0.0214	0.0644	0.0114	0.0097	0.0126	0.0054	0.0469	0.0277	**0.0024**	0.0124	0.0051	