Masters Program in Geospatial Technologies

A GIS-based fire risk mapping and mitigation scenarios fire crisis assessment in Tabriz

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Dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science in Geospatial Technologies

A GIS-based fire risk mapping and mitigation scenarios fire crisis assessment in Tabriz

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Abstract

This project presents a comprehensive evaluation of fire risk in Tabriz city, focusing on twelve key factors to assess varying susceptibility levels. Employing the Spatial Decision-Making System (SDMS) and Analytic Network Process (ANP) methodologies, the study produced a detailed risk zoning map categorizing regions into very low, low, moderate, and high-risk categories.

Motivated by Tabriz's historical significance as one of Iran's most culturally rich cities, designated as a UNESCO World Heritage Site, and the lack of a comprehensive study on fire risk mapping and crisis assessment in the area, this research fills a critical gap. Given the city's unique architectural heritage, characterized by non-standardized buildings and narrow streets, the need for a tailored approach to fire risk management becomes imperative.

In addition to assessing fire risk, the study integrates network analysis, particularly service area tools, to evaluate fire station accessibility citywide. By aligning the fire risk map with traffic network analysis results, specific areas requiring urgent attention for fire prevention and crisis management are identified, especially within historical sections.

The findings of this research provide actionable insights for decision-makers and urban planners in Tabriz, aiming to enhance the city's resilience against fire emergencies. The risk zoning map, alongside network analysis, serves as a valuable decision-making tool, guiding proactive strategies to mitigate fire incidents' impact. Attention is directed towards areas in the north and northwest requiring improved infrastructure or accessibility paths for timely intervention.

1 Introduction

In the face of rapid urban expansion, especially in mid-sized cities, addressing the looming threat of fire is imperative. Vulnerabilities stem from factors such as inadequate firefighting infrastructure, the use of flammable heating materials, poverty, and insufficient disaster prevention programs (Masoumi et al., 2019). The spatial organization of human settlements compounds these vulnerabilities, underscoring the need for a thorough understanding of how settlement patterns impact fire risk in the context of effective urban planning (Yu et al., 2020).

Essential for mitigating urban fire impacts, fire risk mapping and crisis assessment heavily rely on geoinformatics, Spatial Decision Support Systems (SDSS), and Multi-Criteria Decision-Making Systems (MCDMS) (Abedi, 2021). Geoinformatics facilitates the collection, analysis, and visualization of spatial data pertinent to fire risk factors, while SDSS and MCDMS provide a structured framework for informed decision-making in fire risk management (Erdin & Çağlar, 2021). Stressing the importance, Moayedi et al. emphasize the pivotal role of fire hazard zonation, and integrating MCDM methods such as the Analytical Hierarchy Process through GIS techniques ensures the generation of precise fire risk maps (Abedi, 2021; Karimi et al., 2021).

To adeptly handle fire risks, decision-makers, including local governments and municipalities, must leverage geographical information systems (GIS) for spatial data storage and query functionalities. The creation of fire maps, as illustrated by a study in the Fatih District of Istanbul, serves as a pivotal tool in fire risk management and the formulation of policies (Kaplan & Kuru, 2019). Furthermore, recognizing the impact of urban flooding is indispensable in the broader context of urban risk assessment and management (Yong, 2013).

The application of fuzzy theory and decision-making algorithms within GIS environments, exemplified by Vadrevu et al., serves to augment the precision and effectiveness of fire risk mapping (Karimi et al., 2021). This integrated approach facilitates the identification of high-risk zones, aiding in the prioritization of resources for fire prevention and response efforts (Gai et al., 2011).

Creating fire hazard zonation maps is crucial for managing the initiation, duration, and resolution of fire hazards, with susceptibility analysis and risk management maps acting as fundamental components for future planning and prevention (Erdin & Çağlar, 2021). Combining MCDM approaches assists in ranking long-term management plans while accommodating multiple objectives essential for comprehensive fire risk management.

This study aims to enhance fire risk management in Tabriz city by integrating Spatial Decision Support Systems (SDSS), Multi-Criteria Decision-Making Systems (MCDMS), and geoinformatics. Through this integration, we will develop a comprehensive fire risk map and crisis assessment tool, incorporating network analysis to provide valuable insights for urban planners. By analyzing spatial data and assessing accessibility to fire departments, we aim to identify high-risk areas and prioritize resources for fire prevention and response efforts, ultimately enhancing urban resilience and safety in Tabriz City.

2 Research Objectives

This study seeks to apply established geoinformatics techniques to Tabriz, Iran, a region facing urgent requirements for thorough fire risk evaluation and crisis management strategies. Tabriz, notably its UNESCO World Heritage Site, the Tabriz bazaar, experiences an average of three fire incidents every two years, alongside various informal settlements and rural areas lacking standard infrastructure. Hence, there's an urgent necessity for a thorough investigation to support urban planners in devising effective remedies.

The primary goal is to devise a detailed fire risk map for Tabriz, with a specific focus on areas characterized by informal settlements, slums, and non-standardized constructions. Through the analysis of twelve key factors like building materials, age, density, and urban layout, the study aims to pinpoint high-risk regions, offering crucial insights for strategic urban development and fire prevention. The central inquiry guiding this endeavor is: "Which areas in Tabriz are at high risk of fire incidents, and how can a fire risk map aid urban planning to alleviate these risks?"

Another pivotal aim is to conduct a network analysis to assess the accessibility of existing fire stations across Tabriz. By evaluating travel times to different parts of the city, especially those with limited vehicular access like narrow alleys and rural locales, the analysis aims to guide decisions on optimal fire station placement for bolstering city-wide fire response capabilities. The corresponding research question for this aspect is: "What is the accessibility of various Tabriz areas to existing fire stations, and which areas encounter challenges regarding timely fire response?"

Moreover, the study endeavors to merge fire risk mapping and network analysis to enrich crisis evaluation in Tabriz. By amalgamating these two maps, the research aims to offer a comprehensive understanding of the city's susceptibility to fire incidents and the necessity for strategically positioned fire stations. This integrated methodology can aid urban planners and crisis management authorities in formulating effective strategies to mitigate potential fire-related calamities and enhance overall urban resilience. The corresponding research question guiding this endeavor is: "How can the integration of fire risk mapping and network analysis bolster crisis evaluation in Tabriz?"

In summary, this research's primary contribution lies in its thorough examination, integrating fire risk mapping and network analysis, to furnish decision-makers in Tabriz with invaluable insights for informed urban planning and disaster readiness.preparedness.

3 Historiography

In the realm of fire risk assessment and mitigation, various studies have contributed unique methodologies and insights. (Gheshlaghi et al. 2011) developed a forest fire risk mapping model using the MCDMS Method and ANP, considering factors such as slope, land cover, and climate. (Karimi et al. 2021) conducted a structured review evaluating forest fire risk prediction studies, employing databases and the Analytic Hierarchy Process (AHP), considering diverse factors like altitude, climate, and biological agents. Banyeh and Adda (Banyeh et al. 2021) took a retrospective cross-sectional approach, analyzing fire incident reports in the Tamale metropolitan area with binary logistic regression, exploring causes of fire incidents, building types, and climatic conditions. These studies collectively enrich our understanding of fire risk dynamics, each bringing a distinct perspective and methodology to the table.

While previous studies have laid a foundation for fire risk assessment, the current thesis uniquely focuses on Tabriz city, employing the Spatial Decision-Making System (SDMS) and Analytic Network Process (ANP) methods. This approach generates a comprehensive risk zoning map tailored to the specific urban environment. The integration of network analysis to identify gap points and the subsequent decision-making process, informed by traffic network analysis, distinguishes this research. In contrast to broader studies by Cheng (Cheng et al. 2015), this thesis addresses the local context of Tabriz, offering a targeted contribution to urban planning and crisis management in the city.

Feizizadeh and colleagues (Feizizadeh et al. 2022) contribute to the literature by employing GIS-based methods to assess urban traffic accidents and model urban gas distribution networks. Factors such as land use, population density, and seismic effects are considered in their analyses. However, the advantage of the current thesis lies in its specificity to the Tabriz context, utilizing a combination of GIS techniques (SDMS and ANP) to provide actionable insights for crisis management and urban planning. While studies like Kaplan and Kuru (Kaplan et al. 2019) focus on mapping fire incidents and evaluating the service area of fire stations in Fatih sub province, the current research uniquely concentrates on the comprehensive assessment of fire risk and mitigation scenarios in Tabriz.

Roya Abedi's (Abedi 2022) study stands out by applying multi-criteria decision-making (MCDM) models to forest fire management, analyzing factors related to forest fire prevention policy. However, the current thesis distinguishes itself through its urban focus, specifically on Tabriz, and its integration of SDMS and ANP methods for a nuanced fire risk assessment. The study by Zhang Yong (Yong 2013), which establishes an urban fire risk assessment system using the Analytic Hierarchy Process (AHP), shares some similarities with the current thesis. Still, the uniqueness lies in the Tabriz-specific analysis and the combination of methods, providing a valuable contribution to the field of GIS-based fire risk mapping and mitigation scenarios. In Table 1 you can find a summary of some literature review that I did during this study.

Table 1.Summary of literature review

Author	Title	Research Objective	Methodology	Factors Considered	Data Sources
Hassan Abedi	Using GIS to Develop a Model for Forest Fire Risk Mapping	Develop a model for forest fire risk mapping	MCDMS,ANP	Slope, aspect, NDVI, land cover, altitude, distance to settlements, distance to road, wind speed, annual rainfall, and temperature	Landsat-8, ASTER sensor, topography maps
Akram Karimi	Evaluating models and effective factors obtained from RS and GIS in the prediction of forest fire risk	fire risk modelling, evaluate the studies on forest fire risk prediction	SID, Google Scholar, Magiran,AHP,	slope, direction, altitude, rain, climate, wind speed, mois-ture, temperature	Satellite images
Moses Banyeh	Fire Incident Statistics in the Tamale Metropolitan Area in the Northern Region of Ghana	analyze fire incident data in the Tamale metropolitan area of a developing country, particularly focusing on the period from January to June 2021	retrospective cross-sectional analysis, binary logistic regression to reveal key factors for fire safety strategies in the Tamale metropolitan area.	the causes of fire incidents (electrical vs. nonelectrical), the type of building (residential, apartment, or compound house), and climatic conditions (dry vs. wet season)	fire incident reports collected from the Tamale Metropolitan office
Zhang Yong	Analysis on Comprehensive Risk Assessment for Urban Fire: The Case of Haikou City	establish an urban fire risk assessment system using the Analytic Hierarchy Process (AHP) and apply it to a specific case study in Haikou	Delphi Method and AHP	Risk of fire accident,Urban vulnerability, Anti-fire capability, Comprehensive fire risk	the data on fire accidents and fire statistics from the past
Roya Abedi	Application of multi-criteria decision-making models to forest fire management	analyze the most effective criteria for forest fire prevention policy in the Arasbaran forest, Iran	MCDM methods (TOPSIS and SAW)	29 factories in 4 categories: Preparedness and Infrastructure, Information and Monitoring, Accessibility and Infrastructure, Community Involvement and Awareness	Data from Arasbaran forest in Iran, focusing on factors related to forest fire prevention policy

Author	Title	Research Objective	Methodology	Factors Considered	Data Sources
Chengcheng Gai	GIS-Based Forest Fire Risk Assessment and Mapping	develop a comprehensive risk assessment model for forest fires, aiming to identify, classify, and map high-risk areas	Spatial analyst, Grey Relativity Analysis (GRA)	Land use, topography, Population density, the value of forest resources, the presence of a forest fire-brigade, watch-tower, and helicopter water sources	land use map,, topography, and meteorological data for the forested areas
Fatih KAPLAN	Mapping fire incidents and evaluating service area of fire stations in Fatih subprovince	assess and mitigate the social and economic losses caused by fires by utilizing GIS	GIS, Service Area tool	Spatial Distribution of Fires, Effectiveness of Fire Response Stations, Cost-Benefit Analysis of GIS Implementation	governmental institutions
Bakhtiar Feizizadeh	A GIS-Based Spatiotemporal Modelling of Urban Traffic Accidents in Tabriz City during the COVID-19 Pandemic	urban road traffic accident hotspots in Tabriz and changes in the total number of urban traffic accidents due to COVID-19-related and mobility restrictions	GIS-based hotspot analysis, The Comap method	. Land use map,) Population Density based on number of people, General distribution of the frequency of accidents and injuries in Tabriz from 2018 to 20	Surveys, local government records
Bakhtiar Feizizadeh	GIS modeling of firebase of urban gas distribution networks and seismic effects in its intensification (case study: Tabriz)	GIS model of fire-based urban gas distribution network and the seismic effects of Tabriz in intensifying fire	MCDM Method(ANP), FANP model	GAS network, Urban Facilities, quality of residential areas, Urban Geography	General government data-based
Liang Cheng	Fire spread simulation using GIS: Aiming at urban natural gas pipeline	analyze the impacts of single-point fires associated with urban natural gas pipelines and the subsequent spread of fires in urban areas	natural gas pipeline network fire model and a GIS spatial analysis framework	the occurrence of single-point fires associated with urban natural gas pipelines and the subsequent spread of fires in urban areas	use of a natural gas pipeline network fire model

4 Theoretical background

Fire risk assessment stands as a pivotal component in devising strategies for fire management and mitigation (Thompson et al., 2016). The utilization of fire risk mapping assumes a critical role in bolstering disaster management endeavors by furnishing a comprehensive quantitative evaluation of regions susceptible to fire hazards. By scrutinizing an array of factors encompassing vegetation, meteorological patterns, topographical attributes, and human interventions, fire risk models can gauge the probability of fire incidents in specific geographical zones. Such insights prove invaluable in formulating efficacious measures for fire prevention, early detection, and response, thereby augmenting the safety and resilience of vulnerable communities. Moreover, the integration of quantitative risk management principles into fire risk mapping facilitates juxtapositions with other natural calamities and established criteria concerning tolerable loss of life, thereby fostering a more comprehensive approach to disaster risk management (Thompson & Calkin, 2011).

Historic cities, characterized by their cultural richness, present unique fire risk mapping challenges due to their architectural structures, narrow thoroughfares, and limited access to contemporary firefighting resources (Thompson et al., 2016). Historic cities and regions, owing to their architectural intricacies and cultural significance, are particularly vulnerable to fire incidents, accentuating the critical need for thorough fire risk analysis in these areas (Thompson et al., 2016). To accurately gauge and map fire risk within these cities, it becomes imperative to consider factors such as historical construction materials, infrastructure, and urban planning. A profound comprehension of a city's historical journey offers invaluable insights into potential fire hazards. Moreover, assessing the present-day functions of historic buildings, whether they serve as residences, businesses, or cultural hubs, aids in pinpointing sources of ignition and vulnerable sectors (Thompson et al., 2016). Crafting a comprehensive fire risk map necessitates a deep dive into the historical, architectural, and societal dimensions of these urban landscapes. This nuanced approach not only facilitates proactive fire prevention and emergency preparedness but also contributes to the preservation of their priceless cultural heritage. Furthermore, fostering collaboration among scientists, conservationists, and property proprietors is pivotal in devising robust fire protection strategies tailored to historic edifices (Thompson et al., 2016). Such collaborative efforts ensure the incorporation of structural integrity and conservation principles into risk mitigation initiatives while ensuring compliance with fire safety standards.

An alternative methodology for developing fire risk maps includes utilizing remote sensing data and satellite imagery to assess vegetation health and fuel moisture levels. Another approach involves integrating historical fire data, mapping fuel types, and analyzing weather conditions to identify areas with heightened fire risk. Additionally, combining various assessment methods such as analyzing fire occurrence frequency, evaluating fuel inflammability, studying post-ignition fire behavior, and assessing firefighting difficulty can contribute to the creation of a comprehensive and accurate fire risk map (Calkin et al., 2011). Similarly, alternative methods encompass utilizing historical fire occurrence data, assessing the flammability of both dead and live fuels, examining post-ignition fire behavior and severity, and considering firefighting challenges (Wybo et al., 1995).

MCDM methods are invaluable for creating fire risk maps. They allow for the integration of multiple factors and criteria to assess the likelihood and potential impact of fire incidents. This allows decision-makers to prioritize areas for fire prevention and mitigation efforts based on the level of risk. Additionally, MCDM methods enable the consideration of various variables such as vegetation density, wind patterns, proximity to water sources, and human activities that contribute to fire risk. By using MCDM methods, decision-makers can make informed choices about resource allocation and develop effective strategies to manage fire risks.(Thompson & Calkin, 2011)

MCDM techniques are utilized in the creation of fire risk maps owing to their capacity to concurrently address numerous criteria and factors. These methodologies aid in pinpointing and ranking areas with heightened susceptibility to fire occurrences (Chuvieco et al., 2010).

The utilization of Multi-Criteria Decision-Making methods for fire risk mapping is justified by their capability to accommodate diverse factors and criteria concurrently. These can encompass variables like vegetation type, fuel load, terrain characteristics, and meteorological conditions. Another rationale is the ability of MCDM methods to integrate expert insights and local knowledge, crucial for accurately assessing fire risk. Moreover, the amalgamation of geospatial information systems and decision support systems can bolster the precision and efficacy of fire risk mapping (Naderpour et al., 2019).

MCDM methodologies are indispensable in the development of fire risk maps, offering the integration of multiple factors and criteria for evaluating the likelihood and potential repercussions of fire incidents. This facilitates decision-makers in prioritizing areas for fire prevention and mitigation endeavors based on the assessed level of risk. Additionally, MCDM techniques enable the consideration of diverse variables such as vegetation density, wind patterns, proximity to water sources, and human activities, all contributing to fire risk. Through the application of MCDM methods, decision-makers can make well-informed decisions regarding resource allocation and devise effective strategies for managing fire risks (Thompson & Calkin, 2011).

In the realm of fire risk mapping, there is an increasing demand for alternative Multi-Criteria Decision-Making (MCDM) methodologies to enhance the accuracy and efficacy of assessments (Thompson et al., 2016). One such approach is the Analytic Network Process (ANP), which presents several advantages within the context of fire risk mapping. ANP enables the integration of numerous criteria and factors, encompassing variables like fire incidence, fuel flammability, fire behavior, and firefighting complexity, into a cohesive decision-making framework. This integration fosters a holistic evaluation of fire risk, considering the intricate interdependencies and correlations among different factors. Through ANP, fire risk analysts can prioritize and assign weights to these factors based on their relative significance, thereby yielding a more nuanced and precise assessment compared to traditional methods. Moreover, ANP accommodates uncertainties and ambiguities associated with input data, enhancing its utility in fire risk analysis (Thompson et al., 2016).

Another potential technique for standardizing criteria scores in fire risk mapping is the Score Rate method. This method entails assigning scores to each criterion based on their relative importance and subsequently normalizing these scores to a common scale. However, ANP surpasses mere score standardization by considering the intricate interdependencies and relationships between criteria. Standardization is a critical process that ensures consistency and reliability across various domains and industries. In utilizing the score rate method for standardization, employing the Analytic Network Process method proves advantageous. ANP facilitates a more comprehensive assessment and comparison of different options or alternatives by accounting for the interdependencies and interactions between various criteria. This holistic approach is particularly valuable in decision-making processes requiring a nuanced perspective. Additionally, ANP aids in prioritizing criteria and identifying the most crucial factors, making it the preferred choice for standardization using the score rate method. By integrating the ANP method with the score rate method, organizations can achieve a more robust and objective evaluation process (Saaty, 2004)

5 Methods and materials

5.1 Description of the study area

This research was carried out in Tabriz, which is situated in the East Azerbaijan province in northwest Iran, as depicted in Figure 1. Covering an expanse of 245 square kilometers and with a populace of around 1.8 million inhabitants, Tabriz holds the position of being the fourth-largest city in Iran. Renowned as the primary economic focal point and metropolitan region in northwest Iran, Tabriz boasts a significant historical legacy, having served as the capital for various realms and dynasties over time. Formerly a pivotal trade nexus along the Silk Road, the city now serves as a crucial center for industry, commerce, and academia, benefitting from its proximity to neighboring nations such as Turkey, Iraq, Azerbaijan, and Armenia.

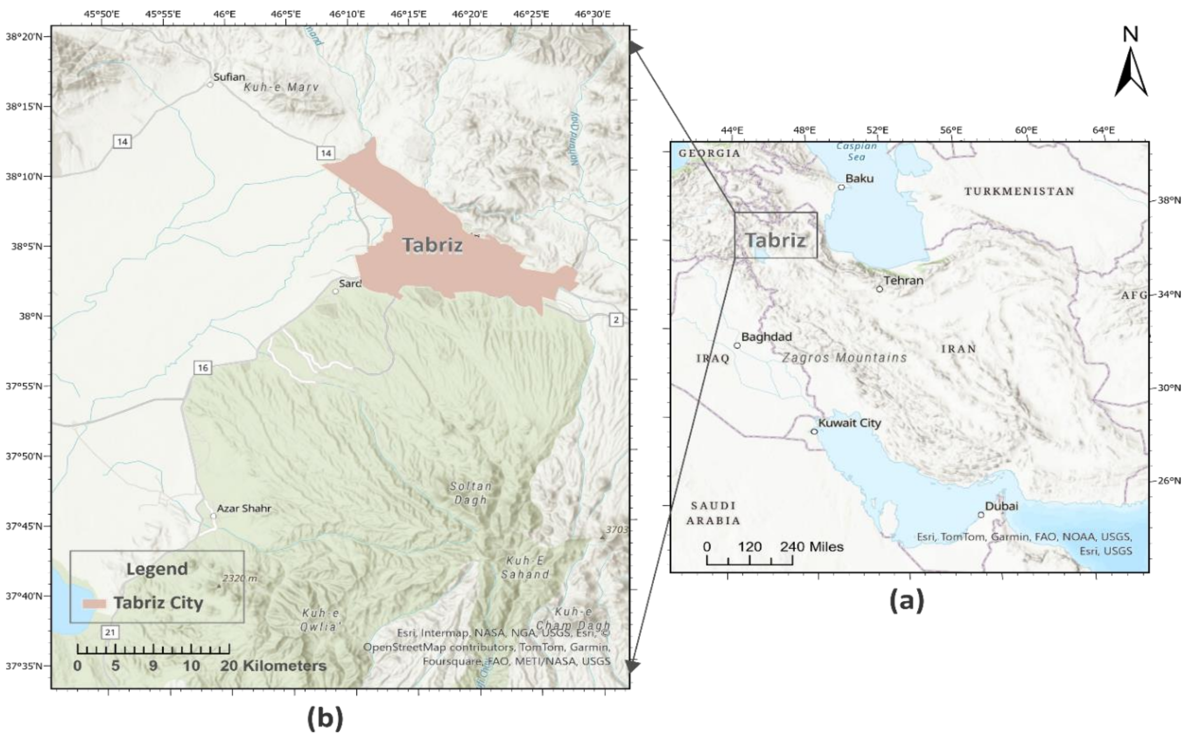


Figure 1.The geographic location of the study area (Tabriz City) in Iran (a) and East Azerbaijan Province in the northwest of Iran (b)

The research on fire risk mapping in Tabriz is situated within a unique socio-economic and historical context. Tabriz's dynamic urban landscape, driven by rapid development in recent years, faces heightened risks, particularly regarding fire incidents. Covering the entirety of Tabriz, this study aims to comprehend and mitigate these risks.

While Tabriz's economic and historical significance underscores its strategic importance, the concentration of socio-economic activities also poses challenges such as traffic congestion. Despite its primary focus on fire risk mapping, this study acknowledges the broader urban context of Tabriz, highlighting the necessity for comprehensive risk assessment and management. Its outcomes seek to enrich fire risk management strategies and inform urban planning and crisis mitigation efforts.

Nestled in the heart of Tabriz is the Tabriz Historic Bazaar Complex, a UNESCO World Heritage Site symbolizing the city's rich cultural and historical heritage. This bustling area, comprising traditional markets, architectural wonders, and communal spaces, epitomizes Tabriz's identity. Renowned for its intricate design and multifunctionality, the Tabriz Historic Bazaar is integral to the city's character, serving as a living testament to its past and fostering cultural exchange. Recognizing its significance, this study includes the historic bazaar in its geographic scope, emphasizing the need to preserve such cultural gems amidst urban development challenges. Understanding the relationship between historical landmarks like the Tabriz Bazaar and contemporary fire risk factors is crucial for devising nuanced and effective strategies in fire risk assessment and urban planning endeavors.

Figure 2. Tabriz Historic Bazaar Complex

Significantly, Tabriz boasts not only the location of the first-ever fire-fighting tower, as depicted in Figure 3 but also stands as the home to the first fire station. This historical milestone, marked in 1917, showcased the city's commitment to fire safety under the leadership of its mayor. The construction of the Yanghin tower, a towering monument in its own right, played a pivotal role in aiding fire detection across the city. Today, the tower remains an integral part of Fire Station Number 1 in the Tabriz Fire Department.

This historical legacy symbolizes the city's enduring dedication to public safety and the evolution of Iran's fire safety services.

Figure 3.Fire Fighting Tower in Tabriz (Yanghyn Tower)

The rapid advancement of urban development in Tabriz brings forth new and developing areas that pose distinct challenges. These zones, lacking well-established road networks and accessible pathways, stand as vulnerable areas in the face of potential fire incidents. Ineffectual transportation routes hinder the prompt response of fire departments, emphasizing the critical need for a comprehensive examination of fire risk in these evolving urban landscapes.

Figure 4.Informal and slams area in Tabriz

One major factor contributing to the heightened fire risk in these regions stems from the construction of buildings lacking adherence to standardized safety protocols. The prevalence of non-standardized structures, characterized by varying materials and construction methods, poses a significant obstacle to both preventing and containing fires. The absence of consistency in building materials, combined with inadequate safety protocols, highlights the pressing need to identify and rectify fire hazards within these specific areas.

Moreover, these newly developed zones often feature non-standard gas pipelines and other facilities, further exacerbating the overall fire risk. The lack of standardized infrastructure, including gas pipelines and utilities, heightens the potential for fire incidents and complicates the implementation of effective preventative measures. A nuanced comprehension of the intricacies within these urban environments is crucial for crafting precise strategies that not only mitigate fire risks but also bolster the overall resilience of Tabriz's evolving urban landscape. See Figure 4 for a visual depiction of these challenges.

5.2 Selection of Criterion

The selection of criteria for this fire risk mapping study is a nuanced process that hinges on a combination of contextual relevance, data availability, and insights from existing research. Unlike rigid, universal criteria, the chosen parameters are tailored to the specific characteristics of Tabriz and its unique urban landscape. The criteria aim to encapsulate the multifaceted nature of fire risk, reflecting not only geographic considerations but also the intricacies of urban development and building standards.

One of the key considerations in criterion selection is practicality and data accessibility. It is imperative that selected criteria align with the availability of data sources to ensure the feasibility of the study. In this regard, the criteria chosen for this study were meticulously curated, considering both their relevance to fire risk assessment and the practicality of sourcing the necessary data. This approach ensures that the study is not only theoretically robust but also operationally viable.

The decision-making process for criterion selection draws upon a rich body of existing literature and expert consultations. References to works by researchers such as Hassan Abedi, Moses Banyeh, Roya Abedi, Bakhtiar Feizizadeh, and Liang et al. (2015) provide a theoretical foundation for identifying key factors influencing fire risk. Furthermore, expert insights and a deep understanding of the study area, gained through consultation with specialists, contribute to refining the list of criteria to those deemed most pertinent to Tabriz.

Additionally, the selection process acknowledges the dynamic nature of urban development in Tabriz over the past three decades. The influx of rural migrants and rapid economic growth has led to the development of marginal areas characterized by buildings constructed without adherence to engineering standards. This historical context underlines the significance of criteria related to building quality, material, and age, providing a holistic perspective on fire risk. A detailed account of the selected criteria, their respective data sources, and the year of data acquisition is available in Table 2, ensuring transparency and replicability in the methodology.

Table 2. List and details of selected criterion for Fire risk mapping

Major Group	Selected Criterion	Data Source	Year
Building	building age	Municipality of Tabriz	2016
	building material		
	building floor		
	building quality		
	building density		
Topography	Slope	Topography map at a scale of 1:2000	2000-2001
	LULC		
Urban	urbun texture	Municipality of Tabriz	2016
	historial texture		
	Gas_Stations		
	Medical center		
	roads		
Fire	Fire department	Central Fire department in Tabriz	2022-2023

5.3 Dataset

The dataset for this study was meticulously sourced from two primary repositories: the Municipality of Tabriz in Iran and the Central Fire Department in Tabriz, with the most recent data available up to 2022. This comprehensive dataset, categorized into five key groups as outlined in Table 3 (topography, buildings, urban features, fire-related variables, and the traffic network), forms the cornerstone for generating a detailed fire risk map and conducting network analysis.

To contextualize the emphasis on building-related variables, it's essential to recognize the unique challenges posed by Iran's developing status. In a country marked by diverse building materials, ages, floor counts, densities, and qualities, standardization in construction practices is often elusive. This variability, particularly in the study area of Tabriz, where a myriad of old buildings exists, accentuates the significance of focusing on building-related variables in the context of fire risk assessment.

Specifically, the dataset captures critical variables such as building material, age, floor count, density, and quality. The emphasis on building-related data is driven by the understanding that the non-standardized nature of buildings in a developing country like Iran significantly influences fire risk scenarios.

In addition to building-related variables, the dataset encompasses crucial information related to topography, urban features, and the traffic network. The inclusion of these diverse data categories ensures a holistic approach to fire risk mapping and network analysis, providing a comprehensive understanding of the multifaceted factors contributing to fire incidents in the study area.

Table 3. all categories of Data

Topography	Building	Urban	Fire	Transportation
Slope	building quality	urbun texture	Fire department	roads
	building age	historial texture		
	building material	Gas_Stations		
	building floor	Medical center		
	building density	LULC		

5.4 Methodology

Here there is a workflow of this study to better understanding.Figure 5 The workflow diagram encapsulates the systematic process employed in this study to assess and mitigate fire risk in Tabriz. Initiated by an extensive data collection phase, the project gathered information on twelve key factors influencing fire vulnerability. The subsequent application of Spatial Decision-Making System (SDMS) and Analytic Network Process (ANP) methodologies facilitated the generation of a comprehensive fire risk map. The integration of geoinformatics, Multi-Criteria Decision-Making Systems (MCDMS), and network analysis played a pivotal role in the creation of this nuanced map. The workflow reflects the meticulous steps involved, from data collection and analysis to the final synthesis of findings. Each stage of the process contributes to our understanding of urban fire risk and informs strategic planning for enhanced crisis management and urban resilience.

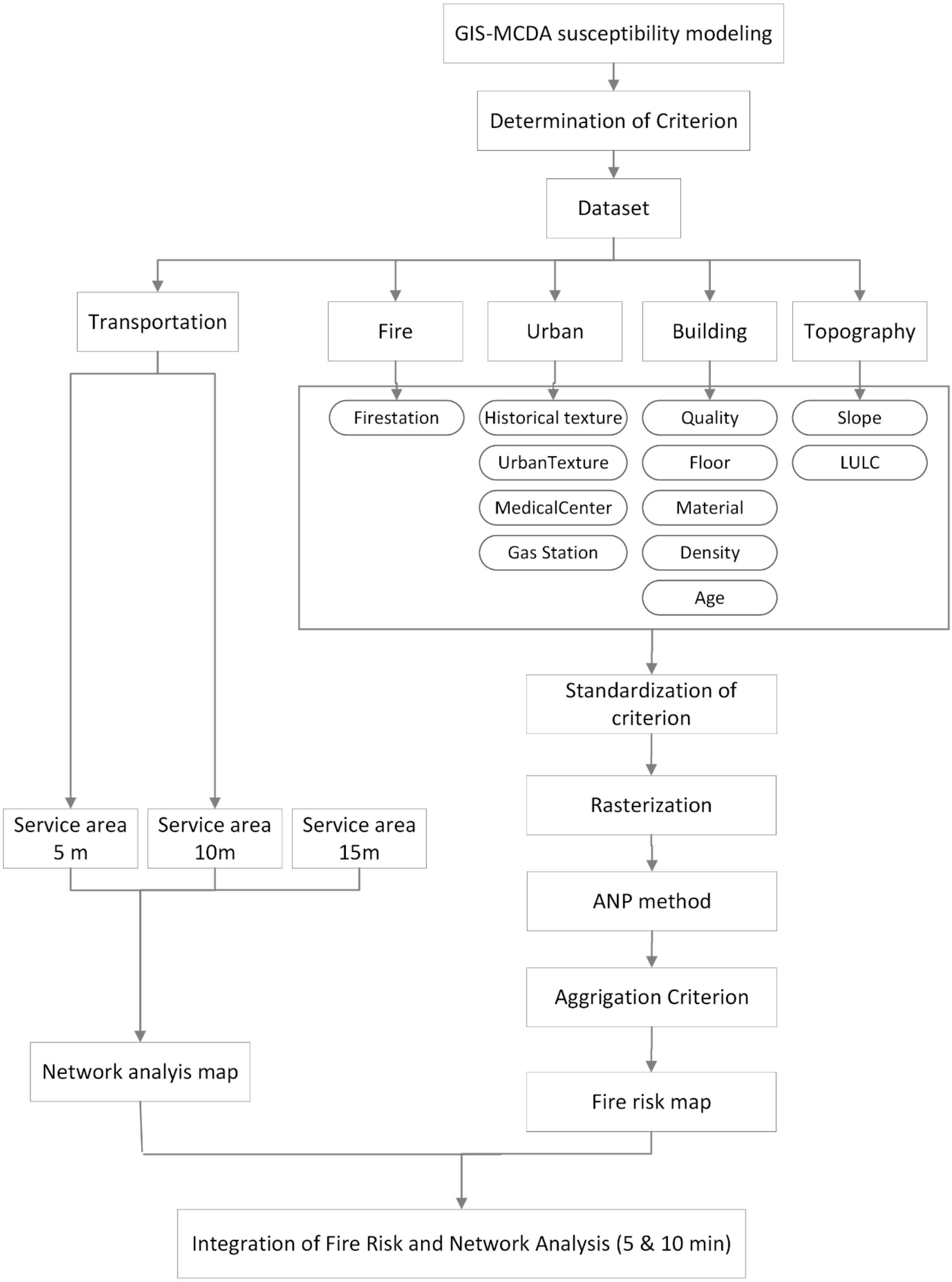


Figure 5. Workflow of the project

5.4.1 Standardization based on Attribute Assignment

MCDM, or Multi-Criteria Decision Analysis, serves as a decision-making method that assesses various factors or criteria collectively. Within the realm of GIS, the term "standardization factors" pertains to the process of converting diverse criteria or variables into a uniform scale or unit. This transformation allows for a purposeful and fair comparison, facilitating the combination and aggregation of different criteria into an overarching decision or ranking (Malczewski, 2006). In the domain of MCDM-GIS, standardization factors play a pivotal role in ensuring the consistency of scales for all criteria involved in the analysis. This consistency promotes an equitable and accurate comparison among diverse criteria and empowers their amalgamation into an overarching decision or ranking. Additionally, these standardization factors address the challenge posed by varying units of measurement or data scales associated with each criterion, fostering a more impartial and objective decision-making process (Greene et al., 2011). The significance of standardization factors in MCDM-GIS extends to enhancing the reliability and validity of analysis outcomes. By facilitating meaningful comparisons and aggregations of diverse factors, these factors contribute to more robust and informative decision-making results (Malczewski & Rinner, 2015).

the score rate method was chosen for standardization due to its flexibility, ease of interpretation, ability to handle diverse data types, transparency, reproducibility, and compatibility with analytical techniques, all of which are essential for conducting rigorous and insightful analyses in our research context.

In the standardization phase, I systematically assigned values to each criterion by introducing a new field named "Value" in the attribute table of each factor. As we can see in Table 4 , These values, ranging from 1 to 5, signify the degree of fire risk associated with each criterion, with 1 representing a lower risk and 5 indicating a higher risk. For instance, considering the building floor criterion, I assigned a value of 1 to buildings with 0-1 floors, reflecting the logic that lower floors correlate with a lower population, thereby reducing the risk of fire. The assignment continued incrementally, with higher values assigned to buildings with more floors, culminating in a value of 5 for structures with 10-28 floors, signifying the highest risk due to increased population density.

Expert consultation played a crucial role in determining values for certain criteria, such as Land Use/Land Cover (LULC). For LULC, the dispersion across the study area was considered, resulting in a value of 1 for wasteland areas (with minimal fire risk) and higher values for categories like Military and Industrial areas, which pose a greater risk. This meticulous assignment process aimed to standardize the diverse criteria, unifying them on a scale from 1 to 5.

This standardization step holds paramount importance as it ensures a consistent scale for factors that originally varied in attributes and scales. This harmonization is fundamental for the subsequent analysis steps in creating a fire risk map. The assignment of values, detailed Table 4, elucidates the unique contribution of each criterion to the overall fire risk assessment. The preparation of factors in a raster format is critical, as it transforms the qualitative nature of each criterion into a quantitative representation, enriching the quality and depth of the final fire risk map. The percentages assigned to each criterion serve as a key indicator of their relative impact on the overall fire risk, paving the way for a nuanced and comprehensive risk assessment.

Table 4. Internal Classification of Research Criteria and Sub-Criteria

Criterion	**Sub-criterion**	**Internal division of sub-criteria**	**1**	**2**	**3**	**4**	**5**
Topography	LULC	wasteland	■				
		Farmland, Natural areas		■			
		Military, Religious			■		
		Transportation, industrial				■	
		Residential, historical					■
	Slope	0-3.5	■				
		3.5-10		■			
		10-20			■		
		20-33				■	
		33-82					■
Building	building quality	0 (Very high Quality)	■				
		1 (high Quality)		■			
		2 (Midrate quality)			■		
		3 (Low quality)				■	
		4 (very low Quality)					■
	building age	0 (<5)	■				
		1 (<10)		■			
		2 (<30)			■		
		3 (<50)				■	
		4 (>50)					■
	building material	0 (Glass, concrete)			■		
		1 (steel)				■	
		2 (wood)					■
		3 (stone)	■				
		4 (Bricks, Rock)		■			
	building floor	0-1	■				
		2-3		■			
		3-5			■		
		5-10				■	
		10-28					■
	building density	0-20	■				
		20-50		■			
		50-100			■		
		100-500				■	
		500-1508					■
Urban	urban texture	Historical boundary/Historical area					■
		1335-1345				■	
		1345-1357			■		
		1357-1370		■			
		>1370	■				
	historical texture	Historical boundary	■				
		Historical area		■			
		Historical buildings			■		
		Historical center				■	
		Historical buildings in city center					■
	Gas_Stations		Euclidean Distance tools				
	Medical location						
Fire	Fire departments						

5.4.2 Rasterization

The process of rasterization played a pivotal role in transforming diverse spatial criteria into a format conducive to comprehensive analysis. Each criterion, including Land Use/Land Cover (LULC), slope, building quality, building age, building material, building floor, building density, urban texture, historical texture, gas stations, hospital locations, fire department locations, and the traffic network (roads), underwent meticulous conversion into raster layers. This transformation facilitated a uniform representation of spatial features across the study area. For each criterion, a dedicated raster was created using the "Feature to Polygon" tool in ArcMap. The assigned values for each pixel in these rasters corresponded to the risk classes ranging from Very Low Risk to Very High Risk, ensuring consistency and comparability across all layers. The resulting raster layers, totaling nine as depicted in Figure 6 to Figure 8 , formed the basis for subsequent analyses.

In the case of point layers, such as fire department locations, gas stations, and medical facilities, which were initially generated using Euclidean Distance tools, an additional step was undertaken to convert them into raster layers. A pixel size of 50 was uniformly applied to maintain consistency across all point-based layers. The maps illustrating these layers and their associated risk classes are presented in Figure 7. This meticulous rasterization process provided a standardized framework for the subsequent stages of attribute assignment and comprehensive risk analysis, contributing significantly to the accuracy and reliability of the Fire Risk Map generated for the study area.

Figure 6.Building Quality (a), Building Material (b), Building Age (c), Building floor(d), Building Density (e)

Value

1	Very low risk
2	Low risk
3	Moderate risk
4	High risk
5	Very high risk

Scale: 1.110000

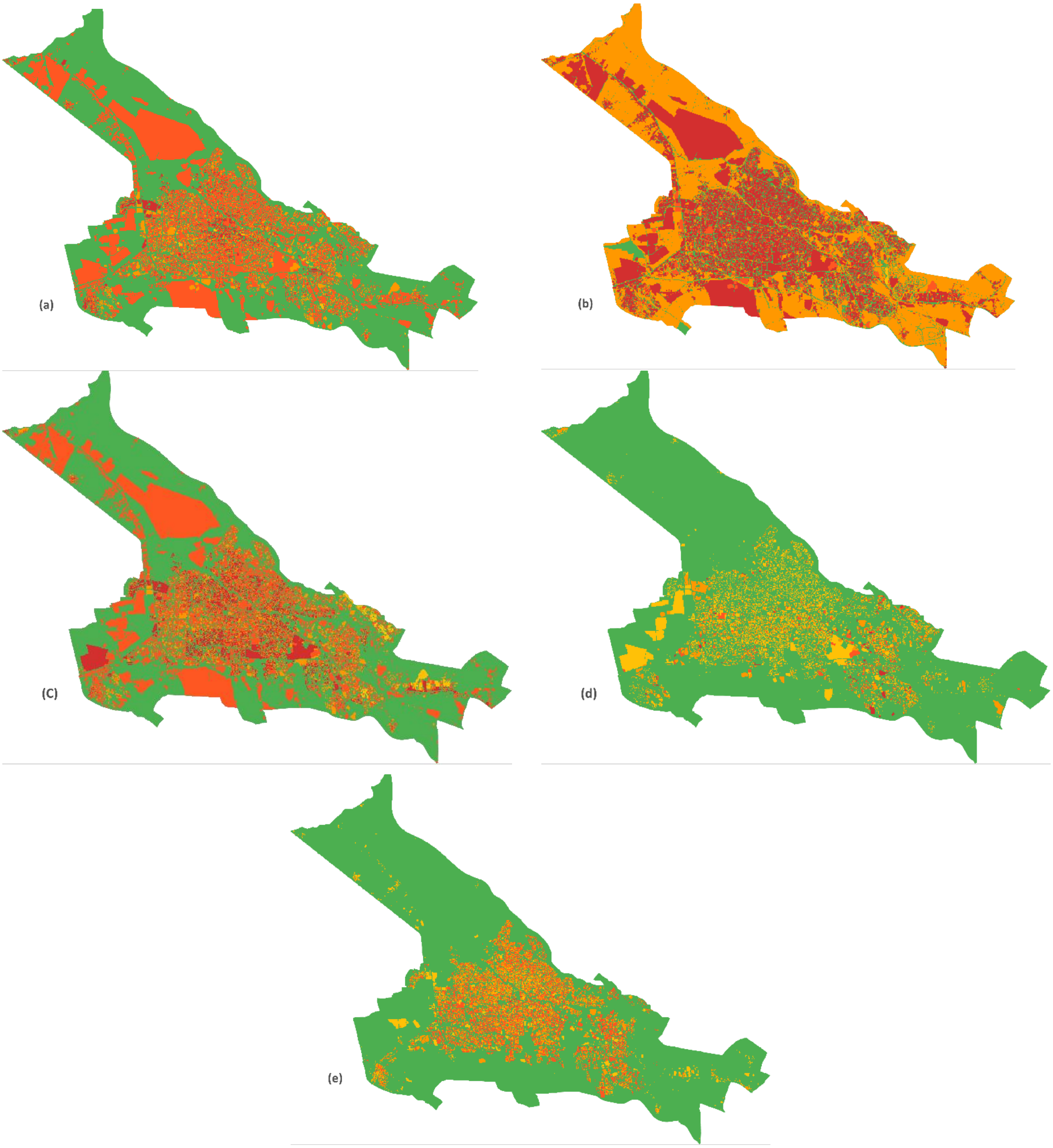
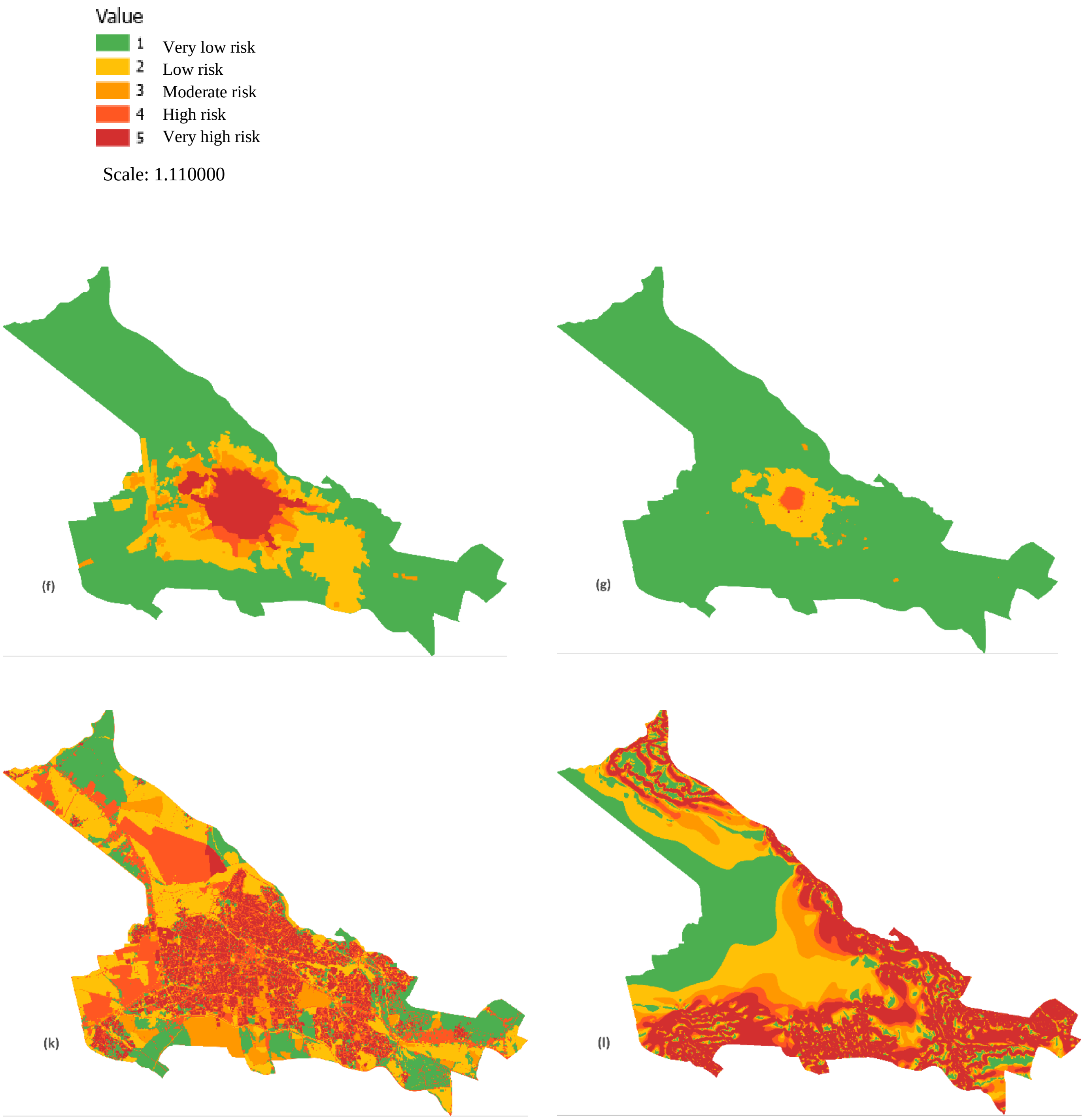


Figure 7.Fire station (h), Medical center (i), Gas station (j)

Figure 8.Urban texture (f), Historical texture (g), LULC (k), Slope (l)



5.4.3 Criterion weighing assignment

Assigning suitable weights to different criteria is essential for making well-informed decisions across various domains, such as the selection of sites for water reservoirs. These weights signify the relative importance and impact of each criterion on the overall decision-making process. Two widely employed methods for determining criterion weights are Saaty's Analytic Hierarchy Process and the Analytic Network Process (Saaty, 2013).

In the process of determining criterion weights, Saaty's Analytic Hierarchy Process and the more advanced Analytic Network Process are valuable tools. These methods empower experts to thoroughly evaluate the weight associated with each criterion, ensuring that their expertise contributes to the analysis of intricate models involving multiple criteria. The utilization of the Saaty and ANP methods enables the acquisition of appropriate weights for each criterion (Saaty, 2013).

The objective of the ANP Fire Risk Map document is to conduct a thorough assessment of fire risk in specific areas, taking into account various critical factors such as safe access/egress, designated areas for occupants and firefighters, and the availability of water supplies and fire protection systems (Masoumi et al., 2019). Utilizing the Analytic Network Process (ANP) method facilitates an effective analysis and prioritization of these factors, resulting in the creation of a fire risk map that identifies high-risk areas (Xiao et al., 2020). This map becomes instrumental in land-use planning and the formulation of strategies to mitigate potential fire impacts in these identified regions.

To enhance the accuracy and reliability of the fire risk assessment, the ANP Fire Risk Map document incorporates data from diverse sources, including field data, satellite images, and national reports (Chuvieco et al., 2010). The application of the ANP method, which integrates analytical and fuzzy logic approaches, ensures that the fire risk map accounts for multiple criteria and subcriteria influencing forest fire occurrences (Gheshlaghi et al., 2019). This comprehensive approach allows for a nuanced understanding of the intricate factors contributing to fire risk, enabling more effective risk management and response strategies.

The ANP method's practical application involved the distribution of a thoughtfully crafted questionnaire to 18 esteemed experts, including researchers and professionals specializing in urban planning from the University of Tabriz, the Department of Urban Planning, and Tabriz Municipality. Figure 9 visually encapsulates the structured questionnaire, an indispensable tool for eliciting expert opinions on various criteria influencing fire risk.

Upon gathering responses from the experts, I meticulously processed their insights using Super Decision software, a robust analytical tool. It's crucial to note that the weights derived from the questionnaires underwent an averaging process. Subsequently, these averaged weights were fed into Super Decision software to produce the pairwise comparison matrix. This meticulous approach ensured a comprehensive and informed analysis of the relative importance of each criterion in the realm of fire risk assessment.

Master thesis in Geospatial Technologies **(WWU University)**

A GIS-based fire risk mapping and mitigation scenarios fire crisis assessment in Tabriz

Dear Experts

Greetings! As part of our ongoing effort to enhance fire risk mapping and develop effective mitigation strategies in Tabriz, I invite your valuable expertise to contribute to our GIS-based assessment. The attached questionnaire is designed to gather insights on twelve key criteria: slope, land use/land cover, building quality, building age, building material, building floor, building density, urban texture, historical texture, gas stations, hospital location, and fire department location. These criteria play a crucial role in determining the susceptibility of an area to fire incidents. The questionnaire represents a weighted matrix where you will assign weights to each criterion based on its perceived importance in the context of fire risk. Your input will significantly impact the accuracy and reliability of our fire risk mapping and contribute to developing effective mitigation scenarios. Your expertise is invaluable, and I appreciate your time and commitment to this crucial assessment.

Thank you for your participation in advancing the fire crisis assessment in Tabriz.

Afsaneh Rasoulian Lafmjani

Name: Years of work experience: Education:

	slope	LULC	B quality	B age	B material	B floor	B density	urban texture	historical texture	Gas Station	hospitals	Fire department
slope	1											
LULC		1										
Building Quality			1									
Building age				1								
Building material					1							
Building floor						1						
Building density							1					
urban texture								1				
historical texture									1			
Gas Station										1		
hospitals											1	
Fire department												1

Figure 9. Questioner

The Analytic Network Process (ANP) method's inconsistency rate plays a pivotal role in influencing the reliability of decision-making processes. Elevated inconsistency rates pose a risk of yielding unreliable results and inaccurate prioritization of both criteria and alternatives. Mitigating inconsistency in the ANP method necessitates a meticulous review of pairwise comparisons involving criteria and alternatives. By scrutinizing the relative importance assigned to each criterion and alternative and ensuring the consistency of these comparisons, it becomes possible to effectively diminish the overall inconsistency rate (Nezamoddini et al., 2011).

Table 5 encapsulates the outcomes of this process, displaying the calculated values or weights assigned to each criterion based on the amalgamated expert perspectives. The utilization of the ANP method allowed for the creation of a comprehensive and detailed matrix, wherein each criterion's importance and influence on fire risk were systematically quantified. The commitment to maintaining an inconsistency rate below 0.1 attests to the methodological rigor applied in the analysis.

This matrix, rich with expert-derived insights, illuminated intriguing patterns. Notably, historical texture emerged as the paramount factor, carrying the highest weight in the assessment. This finding underscores the significance of historical context in shaping fire risk. Conversely, the Medical Center received the lowest weight, potentially indicating the institution's robust fire safety measures and preparedness. The nuanced understanding gained from this comprehensive analysis enhances the reliability and applicability of the subsequent fire risk map, contributing to more informed decision-making and proactive risk mitigation strategies.

Table 5. Pairwise comparison matrix

Criterion	Weights based on the ANP method
Building Density	0.1567
Building age	0.0408
Building Material	0.0873
Building quality	0.0169
Building floor	0.1532
LULC	0.0612
Slope	0.0101
Fire station	0.1890
Gas station	0.0231
Medical center	**0.0042**
Historical texture	**0.2521**
Urban texture	0.0055

5.4.4 Aggregation function

To execute Weighted Overlay Analysis as part of your Multi-Criteria Decision Analysis, it is essential to integrate an aggregation function. This function plays a crucial role in combining various layers of criteria, each assigned specific weights, to arrive at a conclusive decision. There are several aggregation functions available, such as Weighted Sum and Weighted Product, each offering unique advantages and considerations. Selecting the appropriate aggregation function is paramount as it significantly impacts the analysis outcome. Once the suitable function is chosen, it can seamlessly integrate into the MCDM process, contributing to a comprehensive decision output (Ishizaka et al., 2013).

In our analytical process, the utilization of Model Builder within ArcMap proved to be invaluable, enhancing our comprehension of the intricate aggregation function utilized. Figure 10 visually illustrates the output of Model Builder, demonstrating the complexities of the decision-making process. Model Builder facilitated the smooth integration of diverse criteria and their corresponding weights, providing a holistic perspective of the weighted overlay analysis. Leveraging this tool not only improved process efficiency but also promoted a clearer understanding of spatial decision-making dynamics. By visually depicting the aggregation function, Model Builder acted as a valuable aid, fostering deeper insight into the relationship between criteria and their roles in shaping the final decision output.

Figure 10. Integrated MCDM-GIS-based modeling for Fire Risk map using a model builder.

Weighted Overlay Analysis involves assigning importance values to individual raster layers, each representing specific criteria like land use, building quality, and historical texture. By integrating these layers using the Weighted Overlay tool, a composite raster is generated, encapsulating the multifaceted influence of various factors on fire risk.

In this phase, the assigned weights from the ANP-derived matrix play a crucial role in determining the contribution of each criterion to the overall fire risk assessment. Higher weights amplify the impact of a particular criterion on the final map, reflecting its elevated significance in influencing the potential for fire incidents. The resultant fire risk map, generated through Weighted Overlay Analysis, vividly delineates areas with varying degrees of susceptibility to fire, offering a nuanced and comprehensive visualization of the city's fire risk landscape.

6 Results

6.1 Fire Risk Mapping

After the weighted overlay analysis, the Fire Risk Map (Figure 11) was generated, providing a comprehensive visualization of fire susceptibility across Tabriz. The map delineates fire risk into four distinct classes, each representing varying levels of vulnerability. In Class 4, highlighted in red, we observe the most susceptible areas to fire, predominantly concentrated in the city center and specific historical districts. These areas exhibit a culmination of factors such as high building density, aged infrastructure, and historical textures, contributing to heightened fire risk.

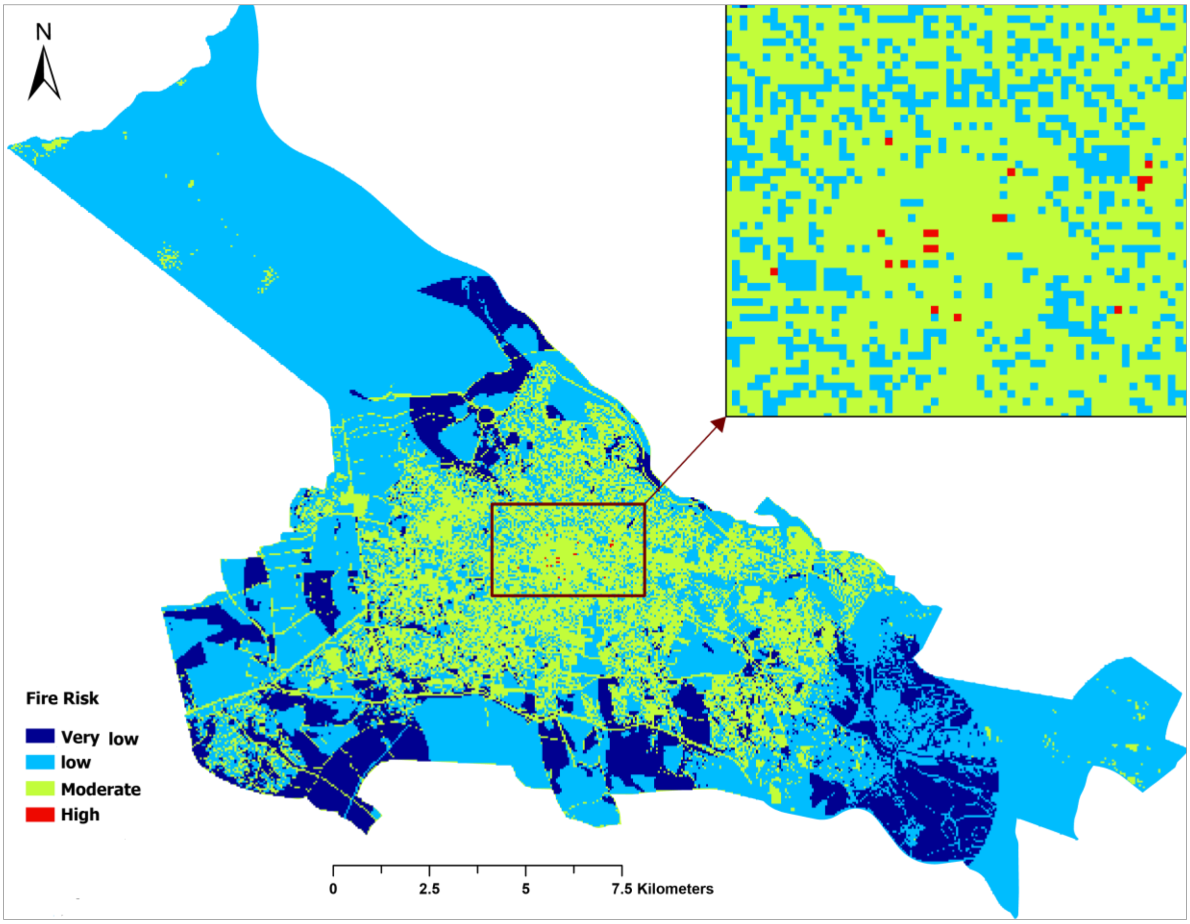


Figure 11.Fire Risk map in Tabriz city

Conversely, the map reveals Class 1 areas, depicted in a different color, representing regions with the lowest susceptibility to fire. Notably, these areas often align with the city's developing boundaries, characterized by modern infrastructure, lower building density, and enhanced fire safety measures.

The classification into risk classes provides valuable insights for urban planning and emergency preparedness. City administrators can utilize this map to prioritize fire prevention strategies, allocate resources, and implement targeted safety measures. The identification of moderate zones, particularly in the city center, emphasizes the urgent need for enhanced fire safety initiatives and infrastructure upgrades in these historically significant yet vulnerable areas.

6.2 Network Analysis

The Network Analysis phase involved the utilization of Service Area tools and network analysis to assess the accessibility of fire department services across Tabriz. To initiate this process, a comprehensive dataset of roads, including highways, freeways, and main streets, was gathered. To ensure the accuracy of our analysis, a topology was created to address potential issues such as overlay errors. Additionally, corrections were made to address concerns like overshooting and undershooting, as well as checking for road disconnections and connectivity problems. These measures were crucial to guarantee the precision of the subsequent network analysis.

The primary objective of the network analysis was to identify areas within Tabriz where the travel time to reach a fire department exceeded 5 minutes. To achieve this, new service area routes were created in ArcMap, incorporating time as an additional factor alongside distance. Figure 12 illustrates the result of this analysis, highlighting areas in Green color where the current fire department coverage may fall short, particularly in the city center. Regions with limited road access within the critical 5-minute timeframe signify potential gaps in emergency response coverage.

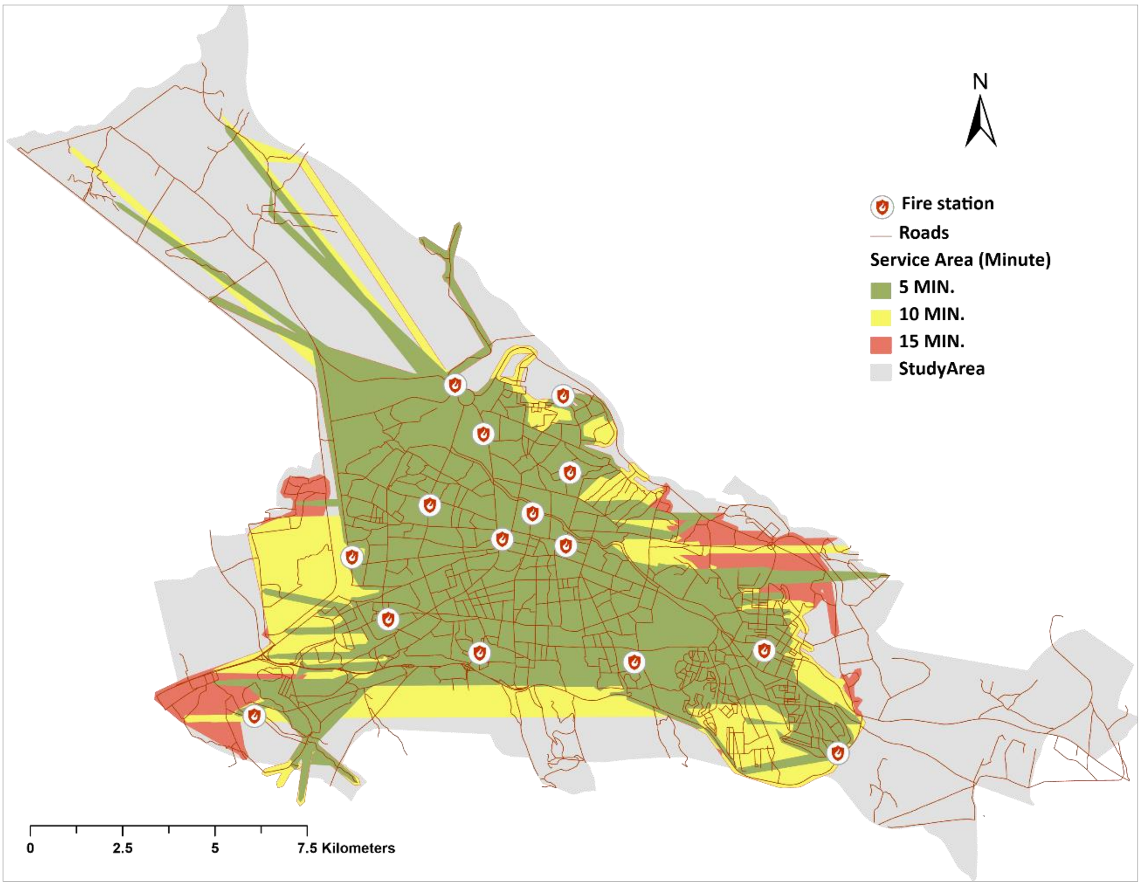


Figure 12.Tabriz city map showing existing coverage of the fire department

In Figure 12, the outcomes of the service area analysis for 5, 10, and 15 minutes are presented. The areas covered by the existing fire department within a 10-minute response time are highlighted in yellow, showcasing the extension of coverage beyond the city center. To further assess the overall service area, a similar analysis was conducted for a 15-minute response time. This additional analysis aimed to determine the percentage of the area that could be reached within this extended time frame. The combined results of these analyses are conveniently visualized in a single map. However, upon closer examination, certain anomalies arise, particularly in areas where fire stations appear to straddle the boundary between the 5-minute and 15-minute service areas. This peculiar occurrence is not indicative of an inefficiency in station placement but rather reflects the challenging terrain and infrastructure present in these regions.

In these specific areas, characterized by a lack of road connectivity or narrow, impassable pathways, traditional firefighting vehicles face significant obstacles in reaching the designated service areas within the prescribed timeframes. Consequently, fire stations positioned at the periphery of these zones serve as strategic outposts, compensating for the geographical constraints and ensuring coverage across a wider expanse. The presence of fire stations at the borderlines of service areas is thus a testament to the nuanced approach required in accommodating the diverse topographies and accessibility challenges encountered in urban environments.

Despite the current coverage, significant portions of the northwest and northeast regions remain inaccessible. These areas are characterized by informal settlements and slums, featuring narrow alleys and staircases, rendering them inaccessible to conventional firefighting vehicles. The inability of existing services to reach these areas efficiently is evident on the map. The identification of such gaps in coverage serves as a valuable resource for urban planners and decision-makers. The map not only highlights the limitations of the current firefighting infrastructure but also provides a basis for strategic planning. It prompts consideration of structural improvements, such as the creation of new roads or access paths, to ensure timely and effective emergency response in these high-risk areas.

However, this network analysis represents just one facet of our comprehensive strategy. The next crucial step involves integrating these findings with our Fire Risk Map to pinpoint areas that not only lack efficient fire department coverage but also exhibit heightened susceptibility to fire incidents. This integration will enable us to formulate strategic recommendations for the placement of new fire department locations, with a focus on areas at the intersection of high fire risk and limited accessibility.

6.3 Integration of Fire Risk and Service Area Maps

The Integration of the Fire Risk Map and Network Analysis constitutes a pivotal stride in achieving a holistic comprehension of the spatial dynamics governing fire risk and emergency response coverage in Tabriz. As depicted in Figure 13, the resultant integrated map offers profound insights into regions characterized not only by heightened susceptibility to fire, as discerned from the Fire Risk Map, but also by the challenges posed in terms of timely access to fire department services, as revealed by the Network Analysis. The primary goal of this study was centered on the integration of the fire risk map and service area analysis, a critical aspect of our comprehensive approach. Through this integration, the study aimed to identify areas with both high fire risk and a pressing need for new fire stations or infrastructure enhancements to facilitate firefighting access.

The amalgamation of these two maps facilitates a nuanced understanding of the dual challenges faced by certain areas. As discussed earlier, urbanization and migration have led to increased population density and building concentration, particularly in the city's outskirts. However, this surge in development has not been met with corresponding improvements in accessibility. Figure 14 and Figure 15 showcase prime examples of these areas, characterized by narrow alleys and a lack of accessible pathways for emergency services. With the integrated map, urban planners and decision-makers gain a comprehensive view of regions where the juxtaposition of high fire risk and limited accessibility demands strategic intervention. The identification of these critical zones serves as a foundation for formulating targeted urban development strategies, encompassing the establishment of new fire stations and the enhancement of accessibility infrastructure to mitigate fire risks effectively.

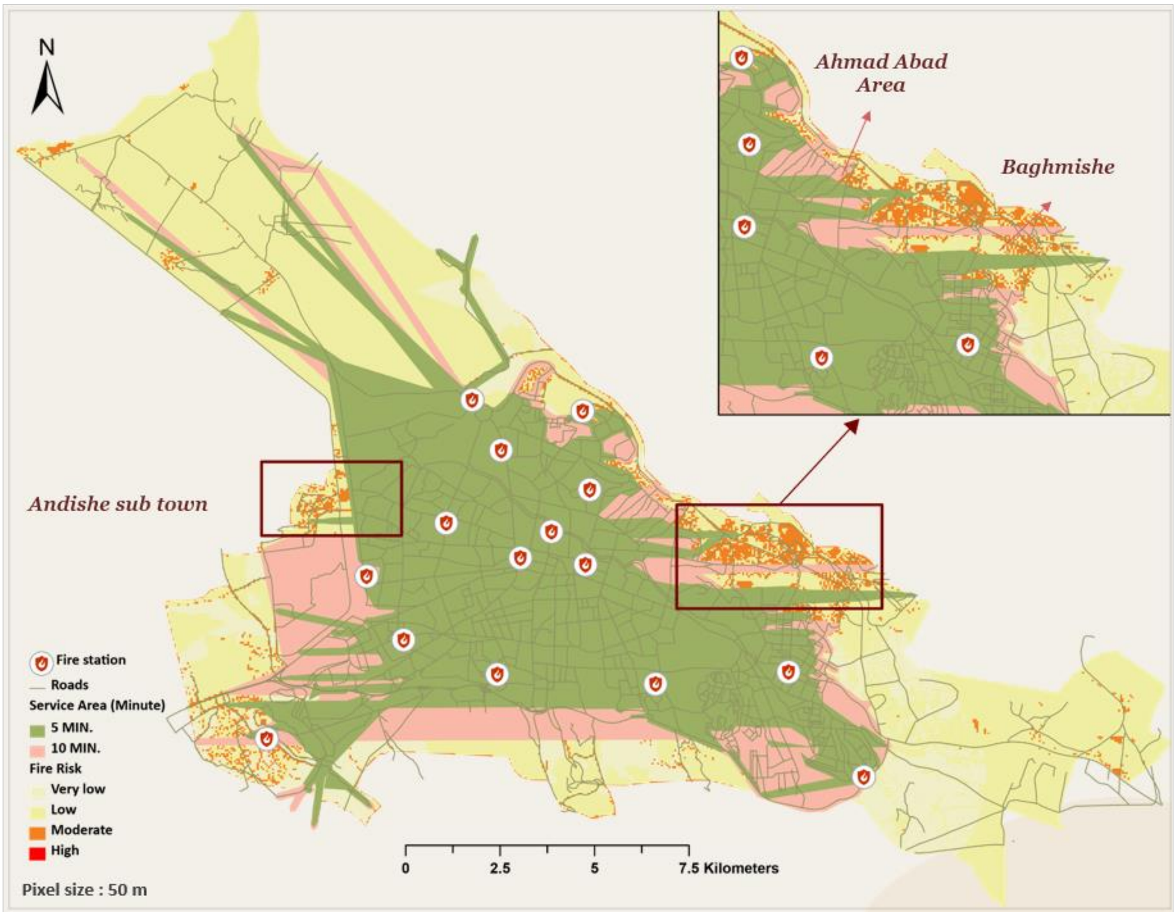


Figure 13.Integration of fire risk map and service area (5 and 10 minutes)

A closer examination reveals specific regions, particularly in the north and northeast of the city, highlighted by the red lines, where the integration of these two datasets signals a pressing need for the establishment of new fire department locations. These areas represent critical intersections of heightened fire risk and limited accessibility, presenting a potential gap in the city's emergency response infrastructure. The identification of these zones is instrumental for urban planners and policymakers in crisis assessment and strategic decision-making.

7 Discussion

In Figure 13, which illustrates the Integration of the fire risk map and service area (5 and 10 minutes), three distinct areas stand out prominently: Baghmishe, Ahmad Abad, and Andishe subtown. Baghmishe, situated in the western part of Tabriz city, earned its moniker as a "town" due to its rapid growth over a short span. Its emergence was fueled by the allure of inexpensive land and construction, attracting a surge of inhabitants. The area, predominantly perched atop mountains, underwent swift urbanization, resulting in a proliferation of structures often lacking adherence to standardized building codes. By analyzing the quality of the ground and identifying areas susceptible to subsidence (as depicted in Figure 14), it becomes evident that Baghmishe faces moderate fire risk. Despite this risk, decision-makers overlooked the crucial aspect of accessibility to fire departments within the standard response time of 15 minutes. This oversight underscores the need for comprehensive urban planning strategies that prioritize both fire safety and accessibility considerations in rapidly developing regions like Baghmishe.

Similarly, the Andishe sub town, located in the east-southeast of Tabriz city, exemplifies similar trends observed in Baghmishe. As depicted in Figure 13 , Andishe subtown also emerges as an area of concern in terms of fire risk and accessibility to firefighting services.

Figure 14. Baghmishe in Tabriz, Photo source www.isna.ir

Figure 15. Ahmad Abad s in Tabriz, High Fire Risk, Limited Accessibility

Another intriguing revelation arising from our study pertains to the Ahmad Abad area in Tabriz (Figure 15), where the absence of fire department services within a 15-minute response time is a concerning reality. This region concurrently exhibits a high level of fire risk, attributed to non-standardized apartment structures, narrow alleys, and notably, the non-standard configuration of gas pipelines. The lack of standardized infrastructure and emergency services in Ahmad Abad underscores the vulnerability of the community to fire incidents. Compounding the issue, the presence of stairs serving as contact points between alleys obstructs any accessible path to reach homes, further exacerbating the challenge. Moreover, the narrow alleys lack sufficient space for fire department vehicles, making it impractical for them to navigate and provide timely assistance. This multifaceted challenge in Ahmad Abad emphasizes the urgent need for strategic planning and intervention by urban planners and decision-makers to address fire risk issues comprehensively and enhance overall urban resilience.

8 Conclusion

In conclusion, this research has successfully achieved its multifaceted objectives, shedding light on critical aspects of fire risk assessment and crisis management in Tabriz, Iran. The development of a comprehensive fire risk map, meticulously examining twelve key factors, has provided valuable insights into high-risk zones, particularly within areas marked by informal settlements, slums, and non-standardized buildings. Notably, the accuracy of our results is exemplified by real-world instances such as the Andishe subtown in the west-south and the Baghmishe and Ahmad Abad region in the north of Tabriz.

Baghmishe experienced rapid growth within a short period, attracting individuals from rural areas and slums due to its affordable land and buildings. However, this rapid urbanization led to the construction of buildings without adherence to standard structural practices. Unfortunately, urban planners overlooked the moderate fire risk associated with this area and neglected to ensure adequate accessibility to fire departments within a 15-minute response time. This scenario exemplifies the consequences of unchecked urban development, underscoring the importance of incorporating safety measures into urban planning processes.

Similarly, the Ahmad Abad region in the north of Tabriz, characterized by informal settlements and narrow alleys, presents a compelling illustration of the challenges posed by unplanned urban growth. The absence of accessible paths for fire trucks and the non-standardized structures within this area highlight the inherent vulnerabilities. These tangible examples from Shahriar and Ahmad Abad not only validate the accuracy of our methodology but also spotlight the pressing need for comprehensive urban planning strategies that consider fire safety and accessibility.

Additionally, the examination of the accessibility of current fire departments through network analysis has raised vital inquiries regarding the city's preparedness for fire emergencies. Our analysis has pinpointed areas situated more than 5, 10, and even 15 minutes away from fire stations, aiding in the determination of optimal fire station locations. This contributes significantly to bolstering the city's capacity for prompt fire response across all areas. The fusion of fire risk mapping with network analysis has emerged as an effective mechanism for evaluating crisis situations comprehensively, granting insights into the city's susceptibility to fire incidents and facilitating strategic fire station placement.

Moving forward, the practical implications of our discoveries are unmistakable. Real-world examples accentuate the relevance of our findings, laying the groundwork for informed and proactive approaches to urban planning and disaster readiness. These outcomes not only enrich academic dialogues on fire risk management but also furnish actionable directives for policymakers, fostering the creation of a safer and more resilient urban landscape for Tabriz residents.

This GIS-based study has significantly contributed to understanding and mitigating fire risk in Tabriz. However, it's crucial to acknowledge inherent limitations in the research process. A notable limitation concerns the availability and accuracy of data. Despite efforts to obtain comprehensive datasets, challenges may exist in obtaining real-time or highly detailed information for certain factors. For example, the precise locations of fire hydrants, crucial in firefighting infrastructure, were unavailable, potentially impacting analysis precision. The study's reliance on historical data might not fully capture the dynamic nature of urban development and evolving risk factors. Another limitation involves assumptions in the ANP methodology, as result accuracy depends on expert opinions and provided criteria weights. The study primarily focused on structural aspects and accessibility, with broader socio-economic factors influencing fire risk not explicitly addressed. These limitations underscore the need for ongoing research and continuous refinement of methodologies to enhance precision and applicability in assessing fire risk in complex urban settings like Tabriz. In addition to the acknowledged limitations, it's important to note another constraint encountered in this study. The absence of precise historical fire incident reports posed a challenge in conducting spatial statistical analyses to further evaluate the results and perform deeper analysis. Without access to detailed spatial statistics, the assessment relied solely on real-world evidence. This limitation underscores the need for more comprehensive data collection and reporting mechanisms to enhance the accuracy and robustness of future fire risk assessments in Tabriz.

A crucial step for future research is to obtain and incorporate historical reports of fire incidents in the study area. By accessing such data, researchers can conduct spatial statistical analyses to evaluate the results more thoroughly. Additionally, integrating information on the duration it took for fires to spread following accidents can provide valuable insights into the temporal dynamics of fire risk. This enriched dataset will offer a deeper understanding of past events and their spatial-temporal patterns, allowing for a more robust assessment of fire risk factors. Moreover, by leveraging historical fire incident reports, researchers can enhance the validity and reliability of their findings. This approach will contribute to a more comprehensive understanding of fire risk management and aid in the development of effective strategies to mitigate urban fire hazards.

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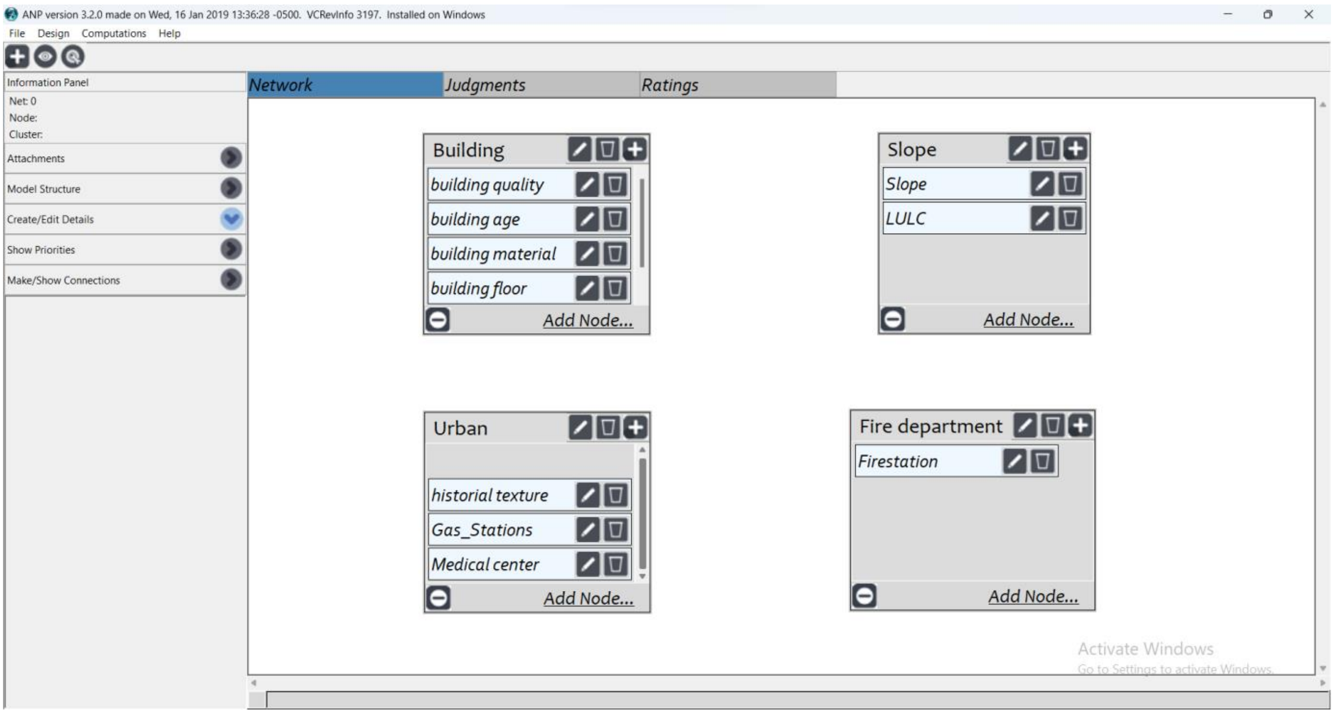
10 Appendix

10.1 Appendix A: Weighted Average of Criteria Weights Obtained from Expert Evaluations for Fire Risk Mapping in Tabriz City

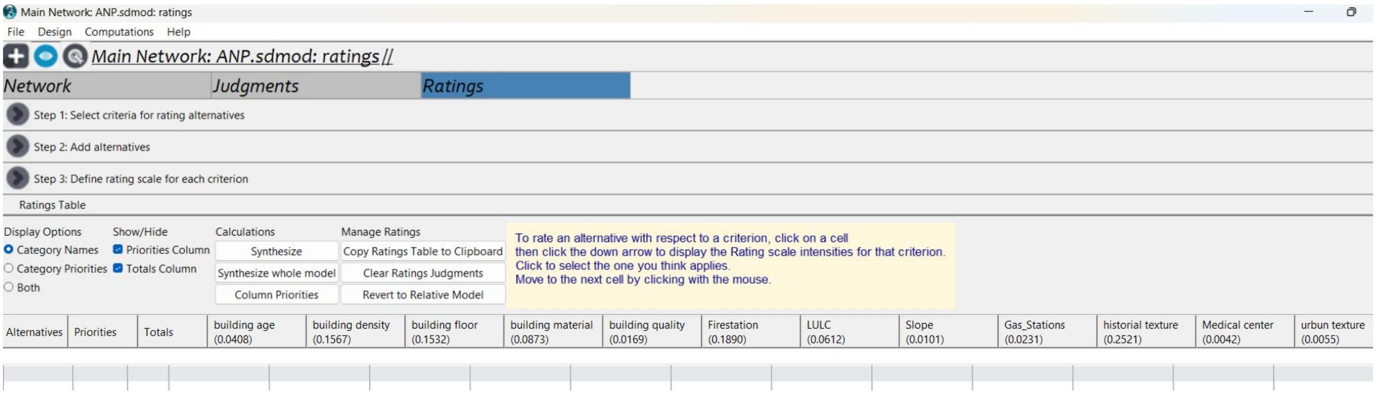
B: Building

	Slope	LULC	B quality	B age	B material	B floor	B density	Urban texture	Historical texture	Gas station	Hospitals	Fire station
Slope	1	1/9	1/8	1/6	1/7	1/5	1/6	1/5	1/8	1/6	1/4	1/5
LULC	9	1	1/7	1/5	1/7	1/5	1/5	1/6	1/7	1/5	1/5	1/4
B quality	8	7	1	1/7	1/8	1/4	1/6	1/5	1/8	1/4	1/5	1/4
B age	6	5	7	1	1/7	1/4	1/5	1/4	1/7	1/3	1/4	1/5
B material	7	7	8	7	1	1/4	1/5	1/3	1/8	1/4	1/3	1/3
B floor	5	5	4	4	4	1	1/6	1/4	1/7	1/2	1/2	1/3
B density	6	5	6	5	5	6	1	1/4	1/5	1/3	1/4	1/4
Urban texture	5	6	5	4	3	4	4	1	1/6	1/4	1/4	1/5
Historical texture	8	7	8	7	8	7	5	6	1	1/7	1/4	¼
Gas station	6	5	4	3	4	2	3	4	7	1	1/3	1/5
Hospitals	4	5	5	4	3	2	4	4	4	3	1	1/5
Fire station	5	4	4	5	3	3	4	5	4	5	5	1

10.2 Appendix B: Strategic Decision-Making: Utilizing Super Decision Software for ANP Methodology Integration



10.3 Appendix C: Super Decision Software: Visualizing Weight Allocation in the RATING Section



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