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AN APPROACH PROPOSAL TO VULNERABILITY ANALYSIS IN URBAN RESILIENCE

Kentsel Dirençlilikte Kırılganlık Analizine Bir Yaklaşım Önerisi

Ayşe AKBULUT BAŞAR

Abstract

This study proposes a spatial multicriteria analysis that can be implemented by the micro zonation technique for any city for the assessment of the vulnerability to the physical environment. Niğde, as the case study, recently had pecuniary damages after a medium-sized earthquake. Although it is not located in the earthquake zone, its damage made it necessary to analyze the vulnerability of the city center, where the population density is the highest. This proposed approach aims that the interventions needed to increase urban resilience in a practical way conducted by the institutions responsible for urban planning so that the damage is reduced in a probable earthquake. According to the results obtained, areas with high vulnerability and areas that need urgent intervention to be made resilient were identified. The population living in the areas that need urgent intervention was determined to constitute approximately one-fifth of the total population of the province.

Keywords: urban resilience, vulnerability analysis, earthquake, Türkiye, Niğde

Öz

Bu çalışma, tüm kentlerde mikrobölgeleme tekniği kullanarak uygulanabilecek, fiziksel çevrede kırılganlığın değerlendirilmesi için bir mekansal çoklu kriter analizi önermektedir. Çalışma alanı olan Niğde, yakın zamanda yaşanan orta büyüklükteki depremden sonra maddi zarar almıştır. Deprem bölgesinde yer almamasına rağmen zarar görmesi, nüfus yoğunluğunun en fazla olduğu kent merkezinin kırılganlığının analiz edilmesini gerekli kılmıştır. Önerilen bu yaklaşım, kentsel dirençliliği artırmak için gerekli müdahalelerin pratik bir şekilde kentsel planlamadan sorumlu kurumlar tarafından yapılmasını ve olası bir depremde hasarın azaltılmasını amaçlamaktadır. Analiz sonucu elde edilen bulgulara göre kırılganlığı yüksek, acil müdahale gerektiren ve dirençli hale getirilmesi gereken alanlar saptanmıştır. Acil müdahale gerektiren alanlarda yaşayan nüfusun, ilin toplam nüfusunun yaklaşık beşte birini oluşturduğu belirlenmiştir.

Anahtar Kelimeler: Skentsel dirençlilik, kırılganlık analizi, deprem, Türkiye, Niğde

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INTRODUCTION

Urban resilience was defined by the United Nations in 2009 as "the ability of settlements, communities, and all systems that are likely to be affected by all types of hazards/threats to have the necessary resources to protect themselves, to secure the functioning of the system, to restructure in a short time, to adapt to change, and to use these resources effectively" (UNISDR, 2009).The concept of resilience first emerged with respect to the stabilization of ecological systems after disasters and their ability to restructure and recuperate to their former condition (Bulkeley & Tuts, 2013; Davoudi et al., 2013; Folke, 2006; Hegger et al., 2016; A. Wardekker et al., 2020; J. A. Wardekker et al., 2010). As the unknowns of the future for cities with complex structure increase, the concept of resilience has become increasingly popular both as a research topic and a policy area in the context of urbanization (Bulkeley & Tuts, 2013; Davoudi et al., 2013; Hegger et al., 2016; A. Wardekker et al., 2020; J. A. Wardekker et al., 2010). Over time, urban resilience has begun to be addressed not only with the ecological aspect but also included administrative, economic and physical terms (Wardekker et al., 2020). The resilience phenomenon, which has become increasingly important since the 2000s, includes discussions on the relationships between the physical, socio-economic and ecological components of cities (Sellberg et al., 2015).

While the concept of urban resilience has been used with reference to understanding ecological changes and balances since the late 1970s, it started to be used in studies on disaster risk reduction as of the mid-1990s (Holling, 1973; İSMEP, 2014). It is no longer correct to consider cities as settlements located in a small and limited geography. With the effect of globalization, it continues its cycles as part of a system that is connected to each other economically and socially at the macro level with invisible ties. (Olcar, 2020). Therefore, the globalizing world, particularly cities having complex systems, cause them to be vulnerable to disasters. Urban resilience has been included among the objectives of urban planning after many international initiatives, especially the United Nations 2030 Agenda for Sustainable Development (United Nations, 2015). Issues such as drought, sea level rise, sudden floods, and tornadoes, which are more on the agenda with global climate change, have entailed the concept of resilience to become even more prominent (Blewitt & Tilbury, 2013; Chelleri, 2012; Kim & Lim, 2016).

For this purpose, the urban planning of the cities have to be made with a disaster-resilient approach, and decisions regarding the spatial organization and functioning of the social system have to be made prior to the disasters. In the "Resilient Cities Report" published by the OECD in 2016, resilience is addressed with four different aspects: economic, social, institutional, and environmental (OECD, 2016). The resilience of a city is assessed based on the extent to which it is able to maintain after the disaster the functioning of the physical and social systems it had before the disaster (Allan & Bryant, 2011; Godschalk, 2003; Mitchell, 2004; Paton et al., 2001).

The ability of cities, where more than half of the world's population resides, to adapt to the pace of today's physical, social, and economic developments, as well as reduce their vulnerability to unplanned developments shows how resilient cities are (Brand & Jax, 2007; Chelleri, 2012; Davoudi et al., 2012; Meerow et al., 2016). Identifying in advance any urban risks that can be faced in the case of a disaster can also help reduce vulnerabilities (Meerow et al., 2016). With the proper identification of risks associated with the disasters, it becomes possible to take precautions for cities by identifying highly vulnerable areas (L. H. Gunderson, 2000; Mitchell, 2004; Ribeiro & Pena Jardim Gonçalves, 2019). The current century has been a period of increasing uncertainties for cities. The need to predicting any unknown problem areas that urban systems are likely to encounter imposes an important responsibility on the field of urban planning (Pickett et al., 2004).

The aim of this study is to reveal the risk situation by making a vulnerability assessment for the built environment/physical environment in the central district of Niğde Province. With the results obtained from this assessment, regions were identified according to the vulnerability and risk level by performing microzonation. In this way, priority intervention areas in the physical environment against probable earthquakes were also determined.

MATERIAL AND METHOD

In urban planning, there are different approaches to measure and assess resilience. These approaches are shaped according to the period such as before, during, and after the disaster, the type of disaster, and the disaster history of the settlements (Tuğaç, 2019). The peculiarities of resilience can be shown as the reason for these different approaches (Cosens & Gunderson, 2018; Sundstrom et al., 2018). Vulnerability analysis can be expressed as a detailed situation assessment tool for disaster preparedness in the pre-disaster process in urban planning science among these approaches (Masnavi et al., 2019). It is not possible to enhance hazard mitigation in every respect for the whole city (Frazier et al., 2014). In urban planning, vulnerability assessment provides the advantage of making cities more resilient by focusing on the functioning of urban systems, discovering their weak points, and reducing risks (Agarwal, 2015; Godschalk, 2003; Masnavi et al., 2019). In this context, it does not directly connect with resilience, but it comprises a basis for susceptibility and mitigation to disaster (Agarwal, 2015). Urban systems can be very comprehensive. For example, there is substantial literature only on social vulnerability (Quarantelli, 1976; Tuğaç, 2019; Usman et al., 2013). Therefore, it should be stated that this study focuses on the built environment of the city. The reason for choosing this method is to confirm with a quantitative study the hypothesis that there is fragility in the built environment of the settlement made with qualitative observations.

Even though studies on resilient cities have been widespread to date, there is no agreed method or theoretical framework on vulnerability assessment (Cumming et al., 2005). The most important precautionary measures in the cities against disasters are regarded to be the adaptation to disasters and mitigation of damages (Blewitt & Tilbury, 2013; Folke, 2010; L. Gunderson et al., 2010; L. H. Gunderson, 2000; Meerow et al., 2016). Here, the vulnerability approach is put forth as the most prominent solution proposal (Bristow & Healy, 2020; Govindarajulu, 2020; L. H. Gunderson, 2000; Mitchell, 2004; Ribeiro & Pena Jardim Gonçalves, 2019). With the vulnerability assessment conducted in the area, targeted sensitivities are identified, risks are revealed, and the important first steps for a city to become resilient are thus taken (V. R. Sharma, 2015; V. R. Sharma & Chandrakanta, 2019).

In Turkiye, examples of disaster-resilient community practices were examined in a study prepared in 2018 by the Ministry of Interior Disaster and Emergency Management Authority (AFAD, 2018). It was seen in studies prepared with the microzonation technique for Istanbul in Turkey that regions were determined based on different hazard potentials and solutions were developed accordingly. Instances among the studies for different countries in the literature were also examined. The sources used for the indicators in the methodology of this study are presented in the table below (Biswanath & Sharma, 2004; Chuang et al., 2020; Inter-American Development Bank, 2010; Sharifi et al., 2021; Suárez et al., 2016; Tilio et al., 2011)(Table1).

Table 1: Resilience concepts in the literature used in the methodology for indicators

Year	Author	Study area	Resilience concept
2004	Biswanath and Sharma	India	Resilience analysis with social, human, psychological, physical, and economic indicators
2010	IADB (Inter-American Development Bank	Latin American and Caribbean countries	Calculation of vulnerability with physical risk factor
2011	Tilio et al.	Italy	Creating multiple layers with the system approach, visualizing the weightages in the layers, and identifying priority intervention areas by prioritizing subindicators according to the phenomenon of resilient city
2016	Suarez et al.	Spain	Developing a method that compares different cities in terms of resilience using an index prepared specifically for city centers
2020	Chuang, Chen, Lin	Taiwan	Developing a resilient city approach based on vulnerability to flooding, ranking the settlements with positive-negative vulnerability technique
2021	Sharifi et al.	Iran	A method of choosing the closest solution to the ideal among alternative scenarios in a physical structure-oriented urban resilience by making social values also measurable

Therefore, the methods addressed here in approaching the phenomenon of resilient city vary according to the study area and scope of the studies. Meanwhile, the scope of the present study is also limited to the built physical environment due to the limited availability of data. Two main features were taken into account when preparing the spatial multicriteria analysis indicators used in the study to perform the vulnerability assessment of the physical environment against earthquakes (Table 2). The first is whether the indicators are composed of indicators that are widely produced and available for cities as it enables practical and quick application. The second is whether the indicator set can be expanded for different studies, which is thought to provide high generality effect, while also being used as a main module. It is expected to facilitate the application, especially in underdeveloped medium-sized cities such as Niğde.

In the vulnerability analysis developed for a possible earthquake scenario, two main issues were emphasized. The first is the risk factor. The aim here is to identify and spatially analyze the risk factors that may cause loss of life and property during or after an earthquake. In this study, which focuses on the analysis of the built environment for earthquake resilience, the risk factors were identified at first. Risk factors are categorized under three main topics: accessibility, open spaces, and structures. Following the risk factors, the indicators of protection factors were identified. The protection factors indicate special elements and areas that need to be protected from earthquakes. In addition, they were selected by considering the technical and social infrastructure elements that can be approached with a conservation approach to minimize the disruptions that may occur during the emergency response after an earthquake. Strategic public service buildings, main service systems, areas of economic activity, and historical cultural heritage represent the protection factors as the main indicator topics.

Table 2: Multiple criteria analysis parameters

Vulnerability to earthquake: Spatial multicriteria analysis in the built environment		
F.1 Risk factor	Parameter	Subparameter
	P.1 Accessibility	Roads narrower than 5 m
		Dead-end streets
	P.2 Sufficiency of open-green areas	Urban open and green spaces
	P.3 Risky Buildings	Structures on the valley floor
		Built-up areas in areas with a slope of more than 25%
		Structures built before the 2007 Turkiye Earthquake Regulation (this indicator can be altered according to the date of the legal process and governance of respective country)
		High-rise buildings with 10 or more floors
		Structures around fuel depots or stations
F.2 Protection factor	P.4 Strategic Public Service Areas	Administrative buildings such as municipality, governorship, family health center, hospital, military areas, general directorate of security etc.
	P.5 Main Infrastructure Systems	Natural gas line
		Power grid line
	P.6 Economic Activity Areas	Industrial Areas
		Trade Areas
	P.7 Cultural Heritage Protection Areas	Protected Registered Structures
		Historical and Cultural Sites with Special Protection Status

In line with the parameters determined by making use of the literature survey, digital data obtained from Niğde Municipality and Niğde Provincial Directorate of the Ministry of Environment and Urbanization were developed and analyzed with geographic information systems. Analyzes prepared using ArcGIS10 and NETCAD 7.6 software programs were evaluated together according to risk and protection factors and their vulnerabilities were revealed. In the study, the microzonation technique developed by Hays (1980) and Sharma and Kovacs (1982) was used to examine the study area in more detail (Hays, 1980; Sharma & Kovacs, 1982) . This technique is based on the idea of dividing the study area into appropriate sized pieces determined according to the area scale for developing the right approach (Sherif, 1982). Here microzonation study was aimed at determining priority intervention areas. For microzonation, the study area was divided into 1 ha squares. The study area covers the central district of the province, for which the data was produced by the municipality, and is 4500 ha in size.

Niğde as Study Area and Earthquake

Turkey, due to its geographical location, is a country that experiences natural disasters such as earthquakes, landslides, and floods. In the last 50 years, 63% of the disaster damages were caused by earthquakes, 21% by landslides, 8% by floods, 5% by rock falls, and 3% by avalanches (AFAD, 2020).

Turkey has been experiencing the transformation of earthquake, a natural phenomenon, into a disaster in a dramatic way for about 80 years. With the Marmara Earthquake of August 17, 1999, the concept of earthquake resilient cities has gained importance in Turkey, particularly due to the magnitude of the earthquake and its wide impact area (Balyemez & Berköz, 2015).

The study area, the central district of Niğde Province (Fig. 1), is a medium-sized city which had a population of 158.257 in 2019, located in the Central Anatolian Region of Turkiye, within the historical and archaeological borders of Cappadocia (TUİK, 2019).

Figure 1: Location of the study area within the borders of Turkey and Niğde Province

The opportunity to respond to natural or man-made disasters becomes more difficult as the scale of the city gets larger and easier as it gets smaller. Medium and small-sized cities can be made more resilient, especially by the virtue of pre-disaster mitigation measures becoming easier to take (Mehmood, 2016). Therefore, the central district of Niğde Province as a case study area can take this advantage with its size and population.

Niğde is located in the low-risk zone according to the earthquake hazard map of Turkiye (Fig. 2)(AFAD, 2020).

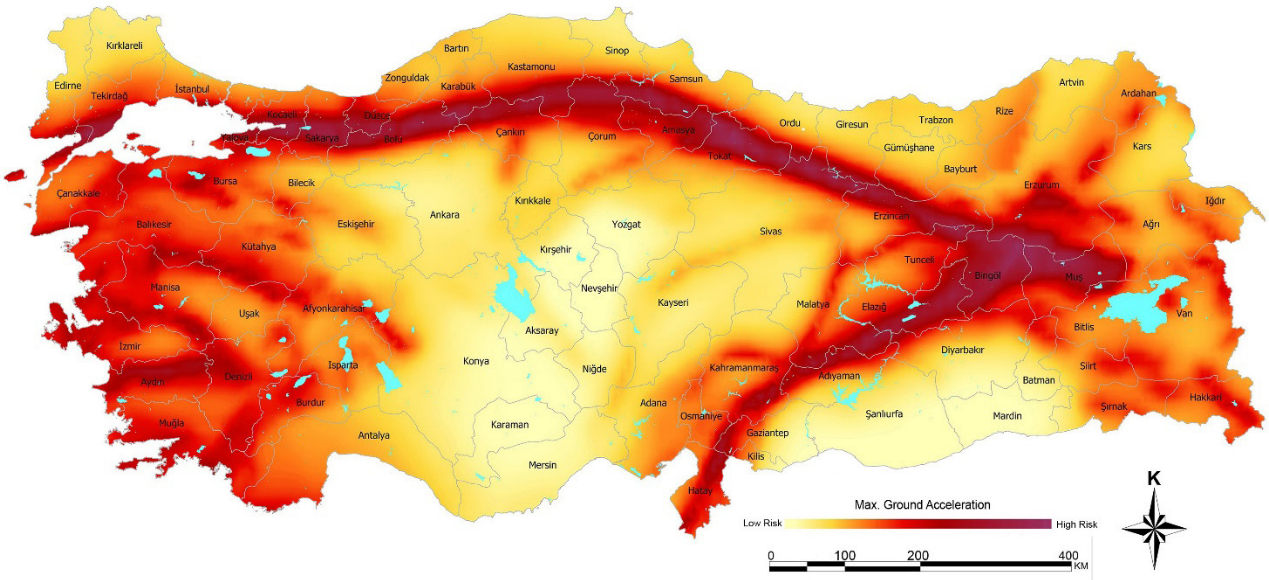

Figure 2: Turkey earthquake hazard map, (AFAD, 2020)

However, it was observed that the earthquakes recorded recently were not very light and mild but were moderate or rarely severe. The most recent earthquake recorded on 21.09.2020 in the Bor District of Niğde with a magnitude of 5.1 caused material damages, despite it being medium-sized and lasting only for 7–8 s (Fig. 3) (Boğaziçi Üniversitesi – Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü, 2020).

Figure 3: Examples of material damages after 21.09.2020 Niğde, Bor Earthquake (Anadolu Ajansı, 2020)

According to the country-wide comparison of the socio-economic development of the cities and their socio-economic vulnerability to disasters, made for Turkiye in 2012, Niğde falls in the group of underdeveloped settlements, ranking second last in the development index on a 5-point Likert scale, and again it ranks in the middle having rated 3 on the 5-point Likert scale for vulnerability (Özceylan & Coşkun, 2012).

With these data, the motivation of this study is to witness the material damage that occurs after a medium-sized earthquake in a district within the borders of a low-risk province, with a lower population, and building density than the city center. After this disaster, it was concluded that the central district of Niğde (Fig.4), where the population density is the highest in the province, needs to be analyzed for vulnerability to earthquakes and its current situation has to be evaluated.

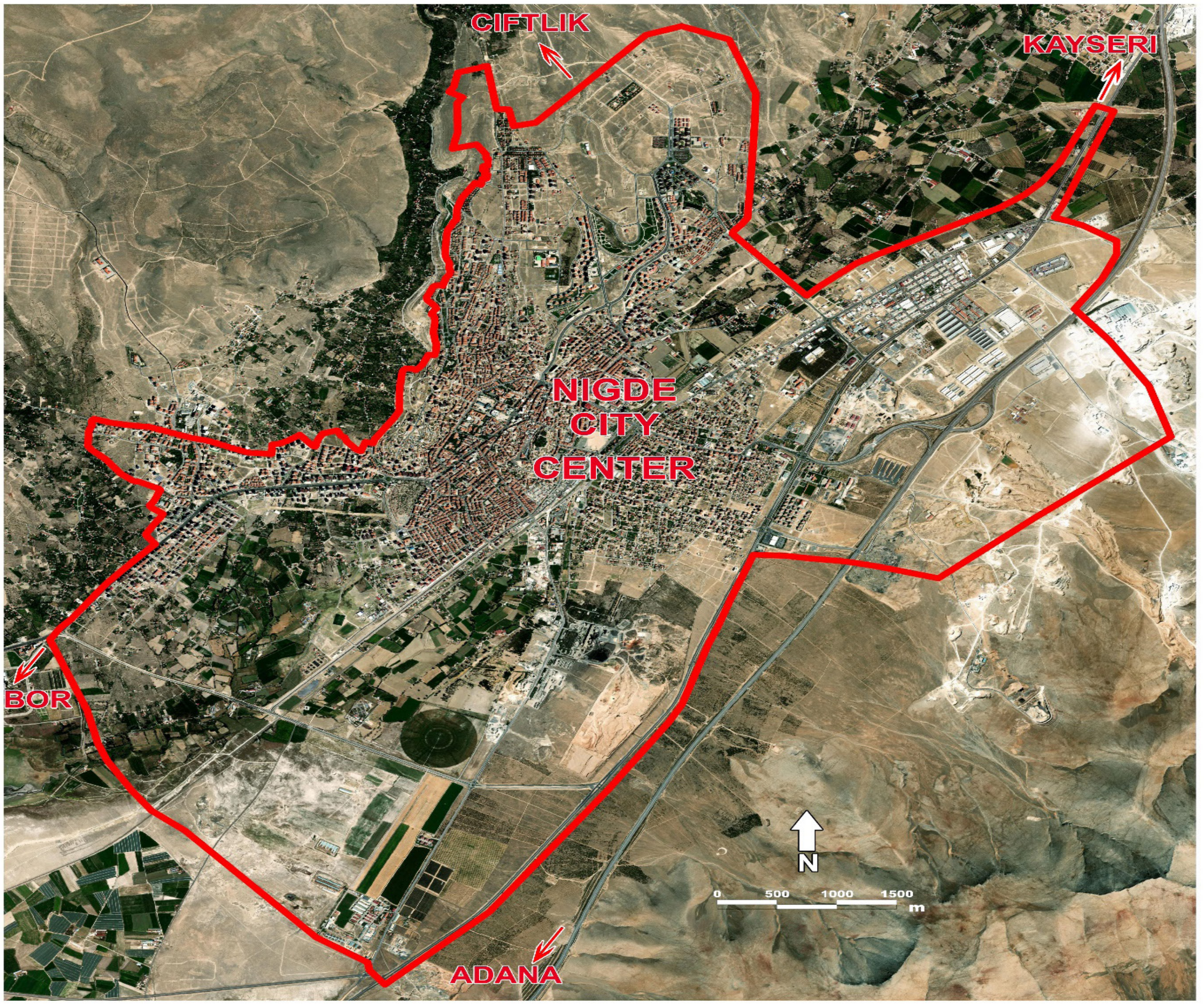

Figure 4: Location of the case study area on Google Earth Map

FINDINGS

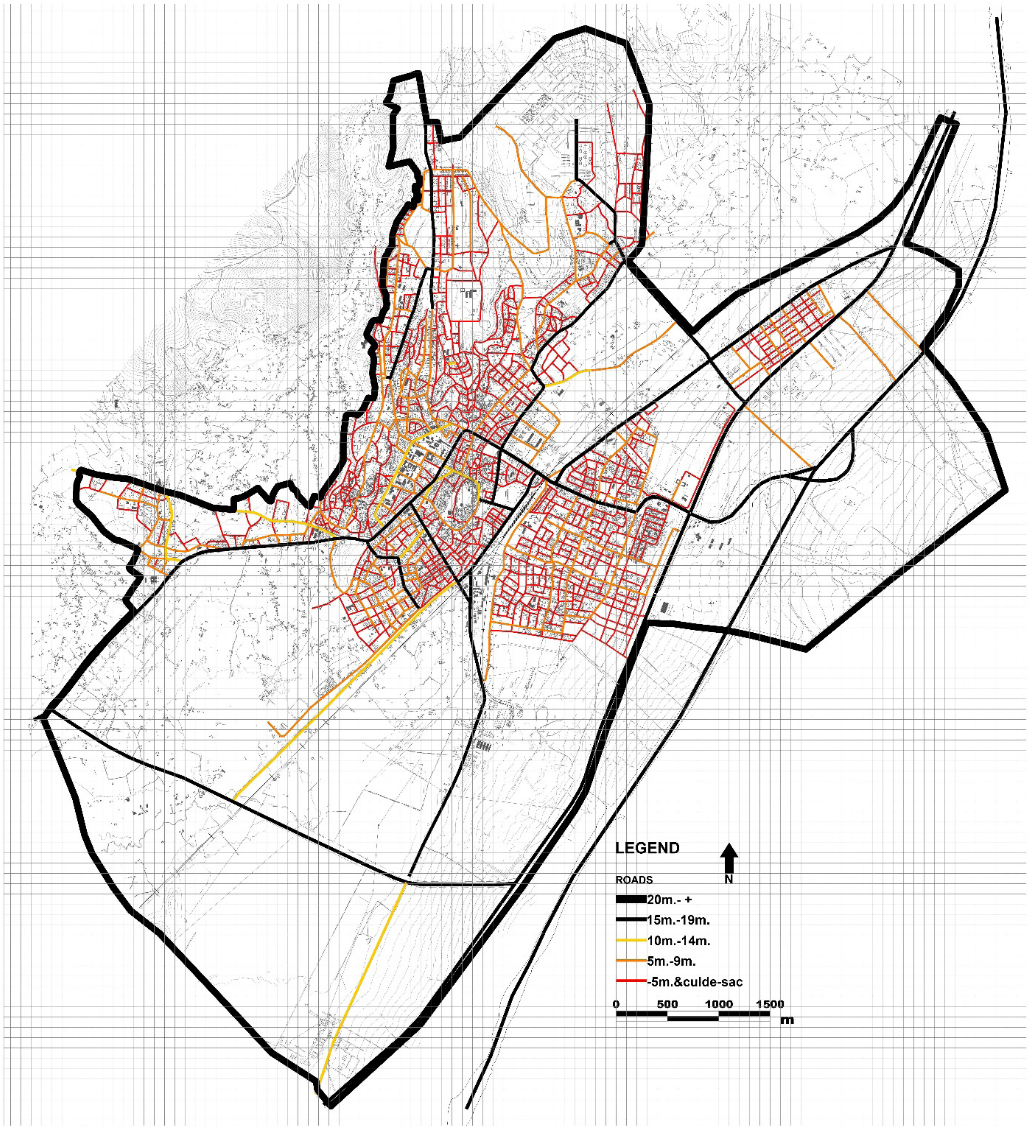

Figure 5: P.1 Accessibility analysis

With the accessibility analysis, the road with road grading, dead-end streets, and roads narrower than 5 m in the indicator set were analyzed (Fig. 5). As can be seen visually from the analysis, there are problems both with the perceptibility of the road grading and density of the narrow and dead-end streets marked in red. Vehicular roads narrower than 5 m restrict accessibility not only at the time of disaster but also in daily life, and have a negative impact on the quality of life. Another problem identified in the accessibility analysis is the linking relationship between the second and third level roads. Continuity cannot be ensured due to roads that do not intersect or complete each other.

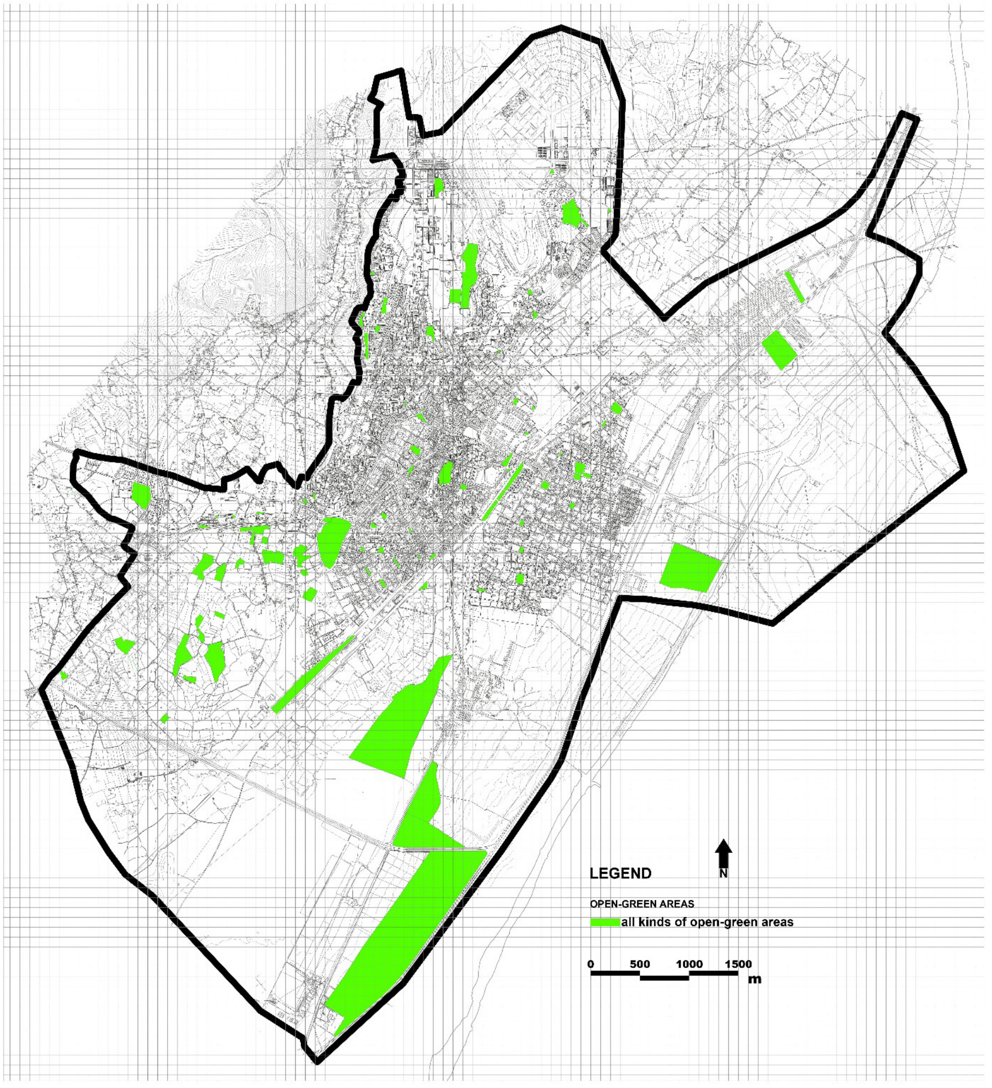

Figure 6: P.2 Analysis of open areas

The first situation that draws attention in the researches on the adequacy of the reinforcement areas for the central district of Niğde Province is the insufficiency of open and green areas (Fig. 6). Open and green areas constitute a total area of approximately 265 ha. After examining the presence of such areas, which are of vital importance during and after disasters, it was found that there is not even 1 m^2 of green space per person in the study area. In the analysis study, open areas with a slope of more than 25%, or surrounded by high-rise buildings with 10 or more floors were considered as intolerance areas and excluded from the analysis. The reason for this intolerancy is about the general principles of urban planning. Sloppy areas that are more than 25% are not suitable for the urban design and open spaces as the emergency muster areas that are surrounded by high-rise buildings (10 or more floors) are not accepted as safe (Aydemir et al., 2004; İmren Güzel, 2021). In this context, it can be said that the biggest risk is the highly limited presence of open spaces that can be used as emergency muster or dispersal areas, especially in the city center.

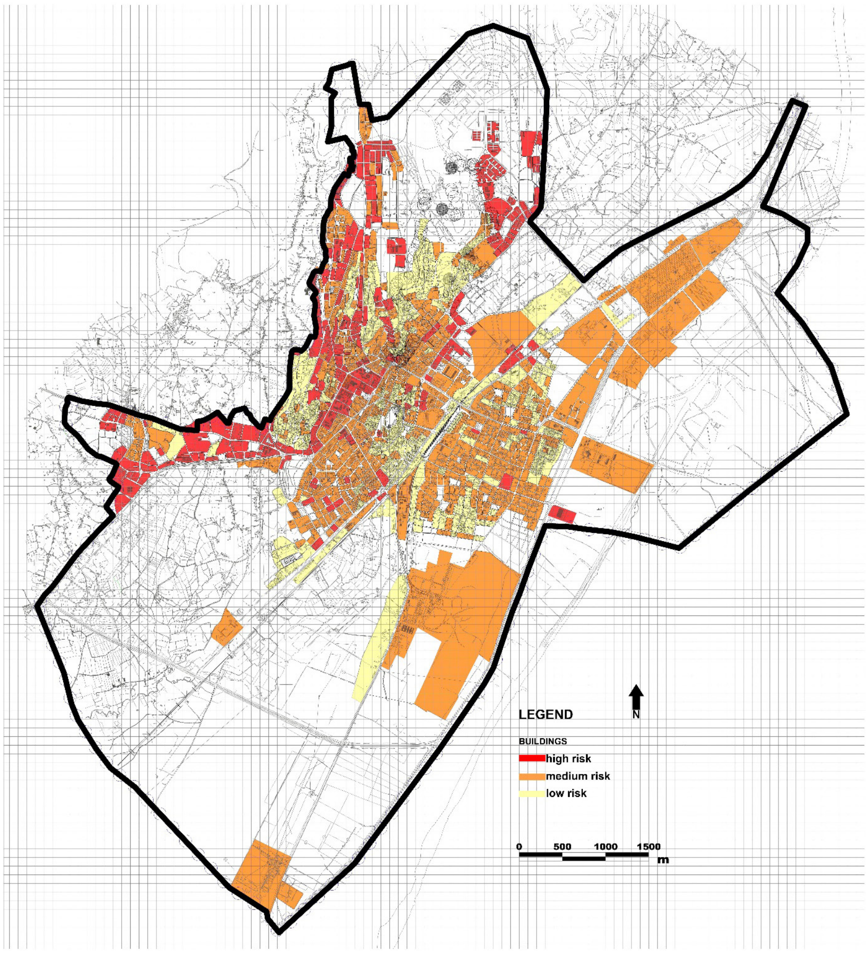

Figure 7: P.3 Analysis of structures

Subindicators used in the analysis of risky structures were incorporated by classifying them into classes as buildings on the valley floor; built-up areas on areas with a slope of more than 25%; buildings built before the Regulation on Construction of Buildings in Earthquake Zones, which is applicable across Turkiye and entered into force in 2007 (this indicator can be altered according to the date of the legal process and governance of respective country); high-rise buildings with 10 or more floors; and buildings around fuel depots or stations (Fig. 7). The structures were marked as low-risk if they fall in only one of these subindicators, as medium-risk if they show up in two groups, and as high risk if they were included in more than two. It has been determined that especially medium-risk areas are spread throughout the city, and high-risk structures are concentrated in the old settlements where the topography is more active.

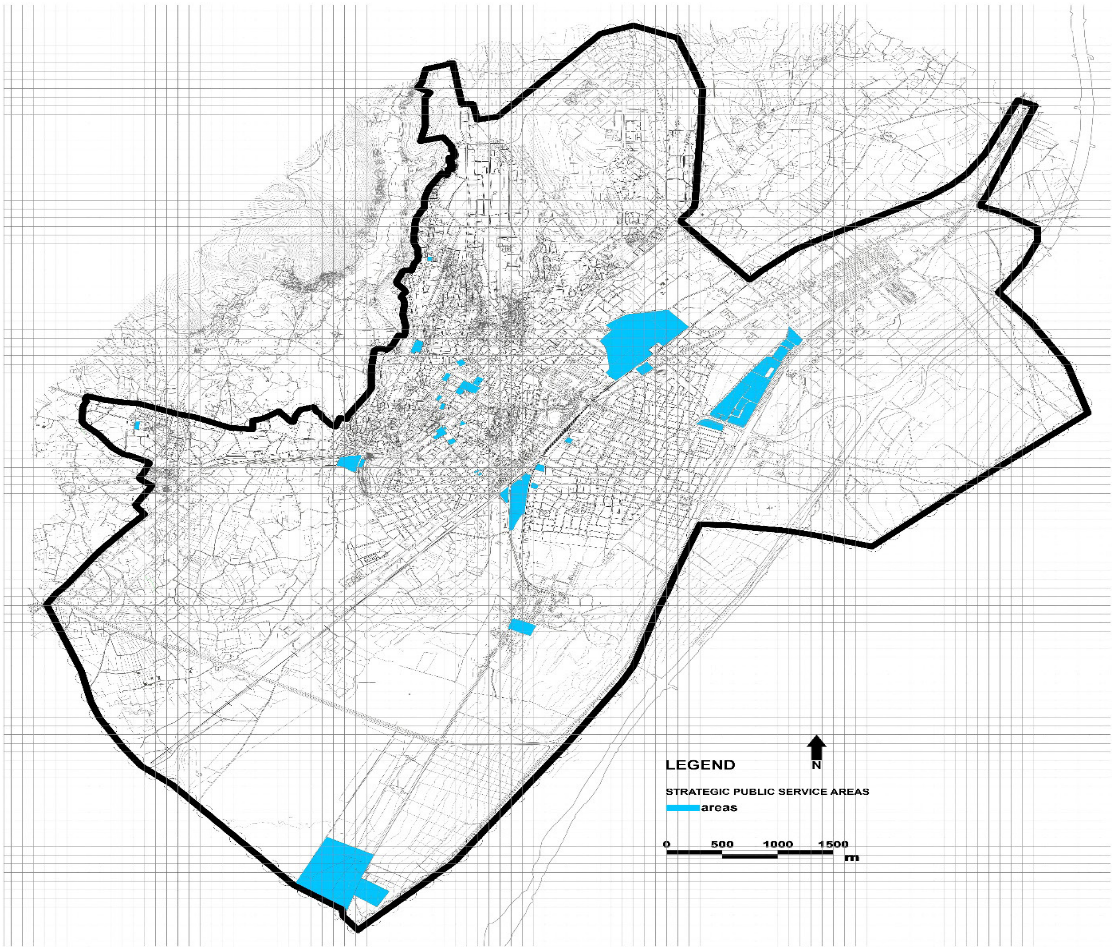

Figure 8: P.4 Analysis of strategic public service buildings

All public service buildings that have strategic importance during a disaster constitute an area of approximately 105 ha (Fig. 8). Such structures are considered important due to their ability to provide services for meeting the needs with a change of function, even after the disaster.

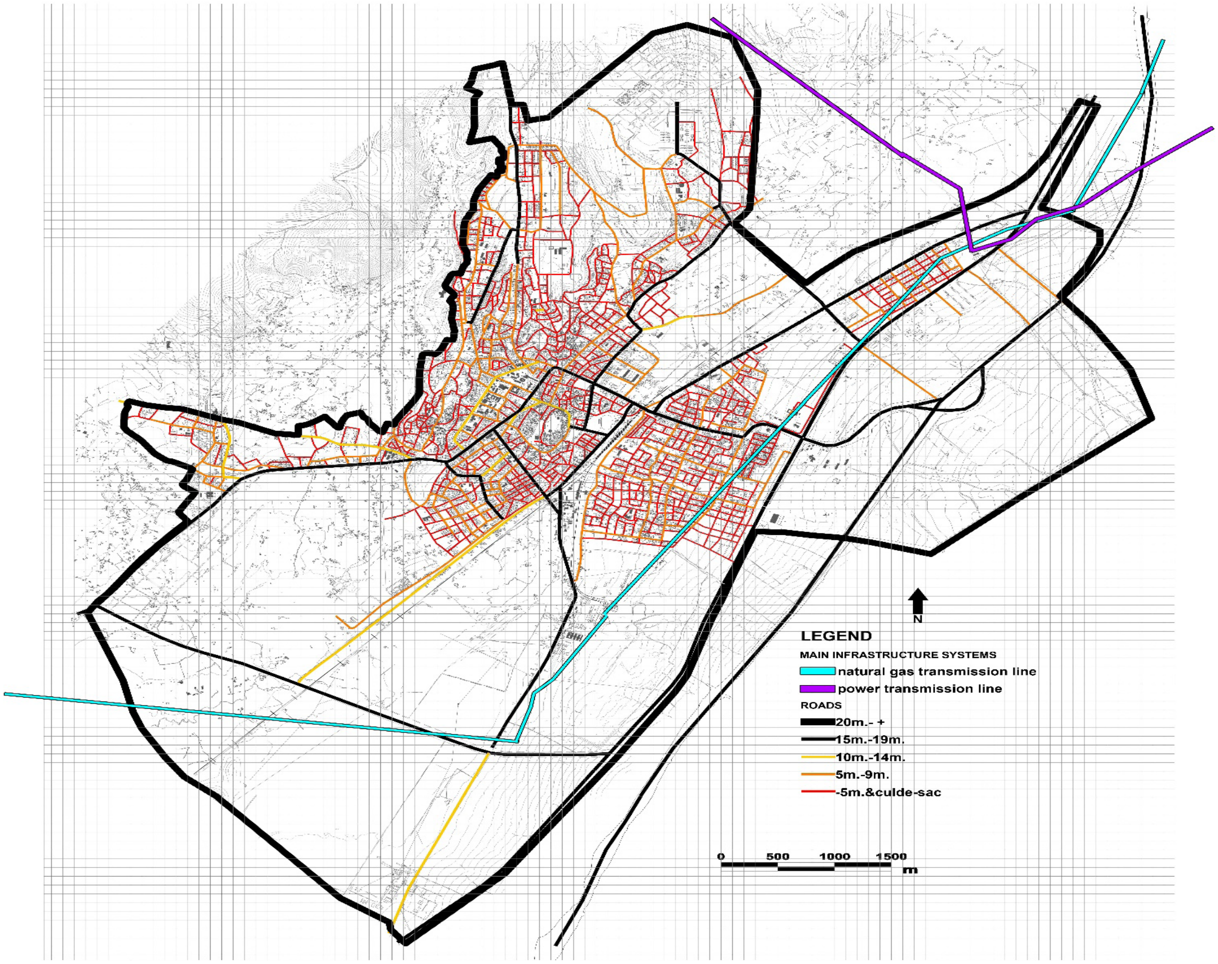

Figure 9: P.5 Main infrastructure systems

There is a possibility that the main centers of energy lines or transmission lines may be damaged during or after the disaster. This may cause a new disaster to occur and prevent emergency aid after the disaster from accessing their targets or prevent the local people from maintaining their daily life due to the interruption of services. Based on the data available in Niğde, the routes of natural gas and energy transmission lines were generally preferred so as to pass through the periphery of the city center (Fig. 9).

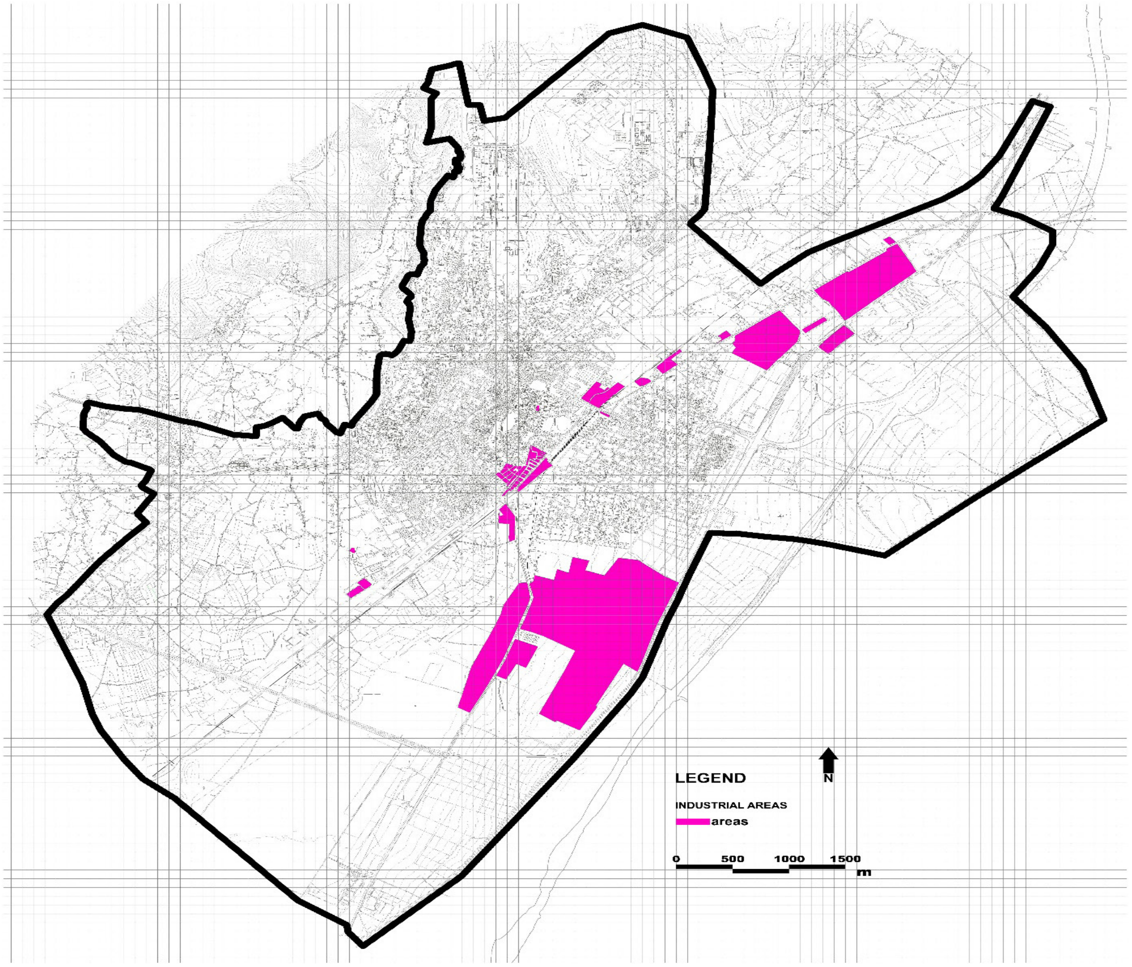

Figure 10: P.6.a. Analysis of industrial areas

The continuation of production in the city after the disaster is an important indicator of its flexibility and resilience. In this context, especially the organized industrial zones and small industrial sites in the city were evaluated under the protection factor (Fig. 10). Together with the storage areas, the total industrial areas in the city constitute an area of approximately 271 ha.

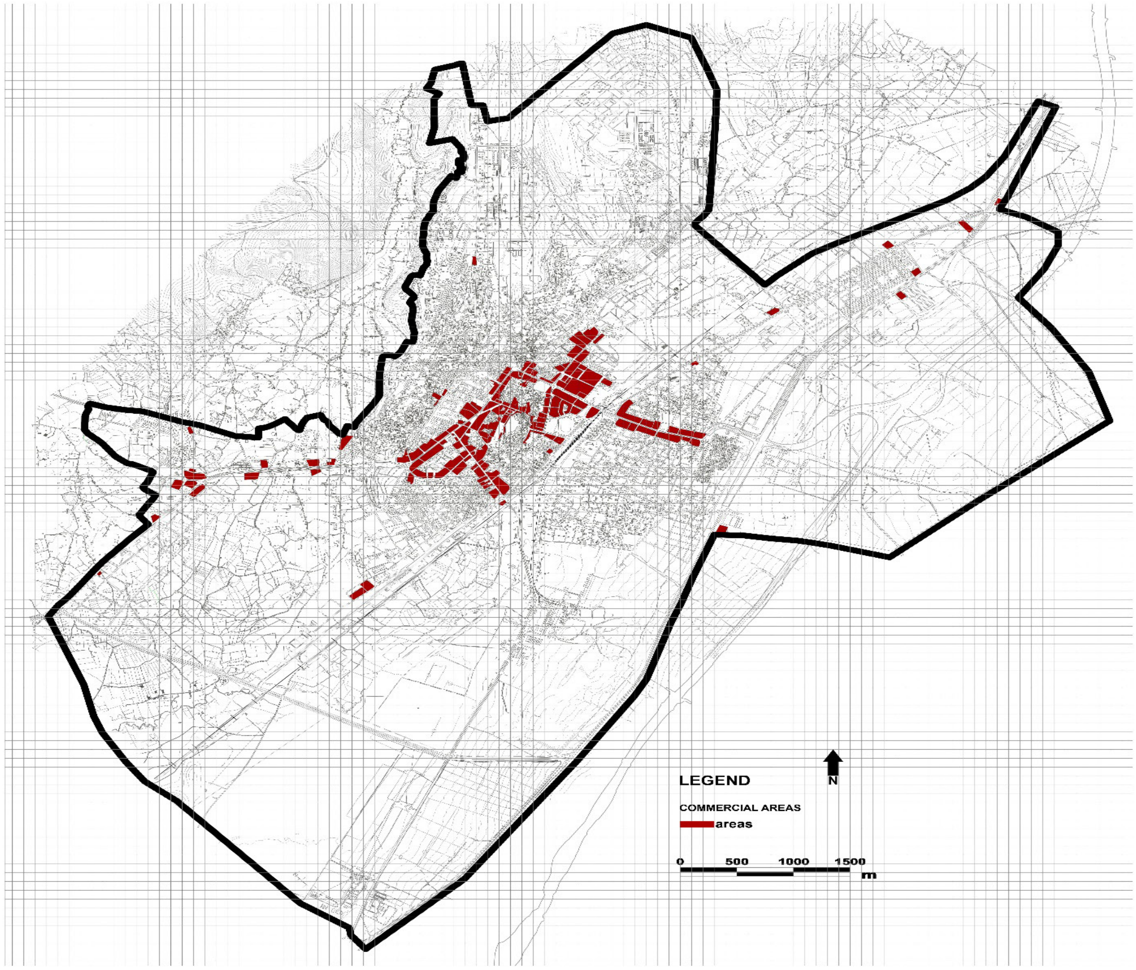

Figure 11: P.6.b. Analysis of trade areas

The commercial center of the city is also located at the same location as the administrative center (Fig. 11). Therefore, there is also a density of buildings, pedestrians, and vehicles. The resilience of this region to disasters is weak and that the risk factor is high.

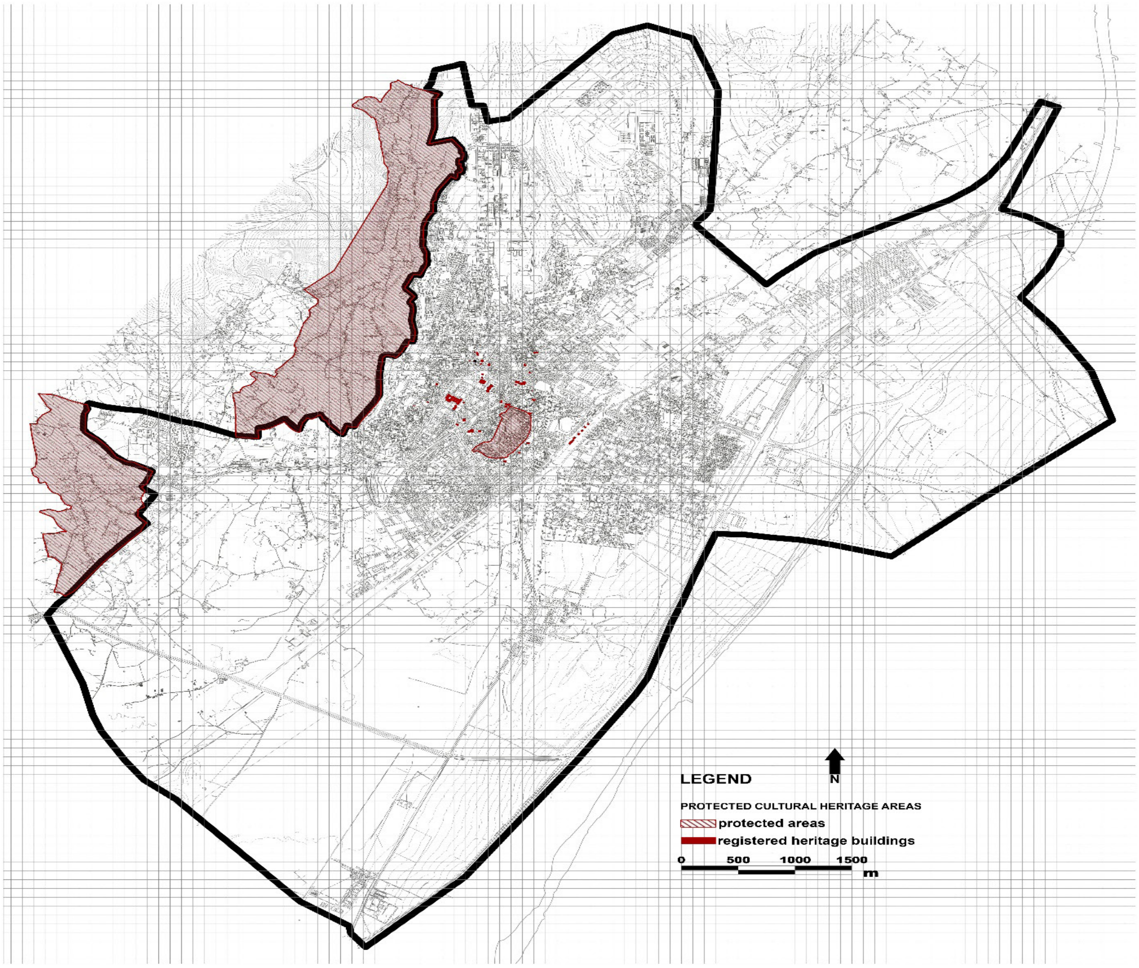

Figure 12: P.7 Analysis of cultural heritage sites

As it is the case across the province of Niğde, the city center also bears the traces of different cultures and civilizations, especially since it hosted the Phrygian, Roman, Byzantine, Seljuk, and Ottoman rules throughout the history (Niğde Valiliği, 2009). There are 116 registered immovable cultural assets, including churches, mosques, tombs, and castles, and three different archaeological, historical, and urban sites (Fig. 12).

CONCLUSION

Owing to the study, the parameters in the risk and protection factors were analyzed. The maps given equal priority weightages in the superposed map bases were spatially overlapped (Fig. 113). Thereafter, these areas were interpreted together with the population density.

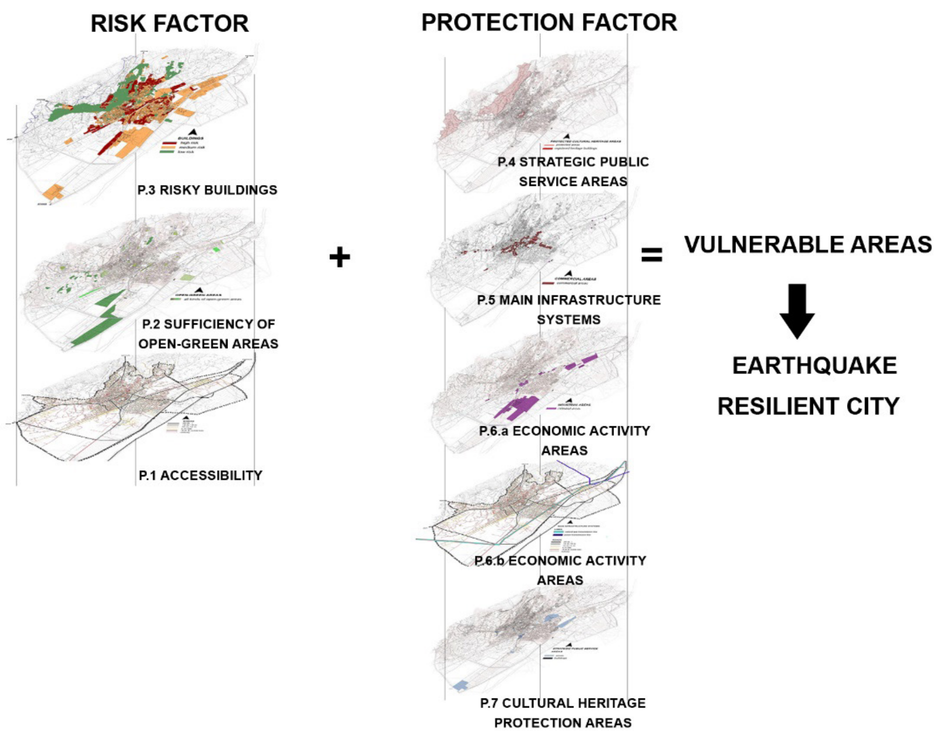

Figure 13: Process of study methodology

According to this methodology, vulnerable areas concentrated in the historical and commercial centers of the city were identified. After superposing all the analyses, overlapping squares of risk factors and protection factors were also combined with the population density (Fig. 14).

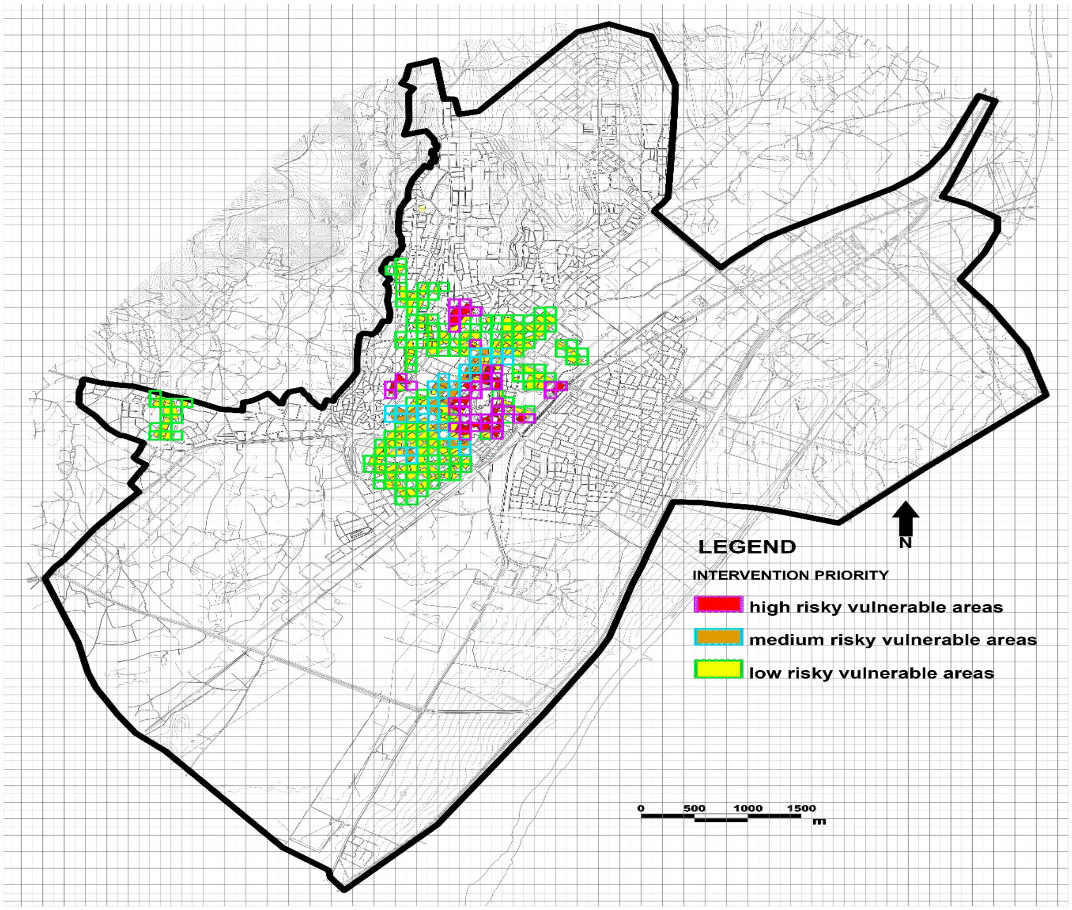

Figure 14: Priority intervention areas in urban resilience to earthquake

Owing to the analysis, it was determined that the high-risk area covers 4.12 ha and requires priority intervention, whereas the areas with moderate vulnerability are 24.78 ha, and areas with low-level vulnerability are 30.96 ha. In this context, it was determined that the area that requires intervention in Niğde covers approximately 2.4% of the study area for an earthquake resilient city on the way to sustainable urban development. When the areas that are likely to be affected by the disaster are analyzed in terms of population size; the urban population living in the high-risk area that require priority intervention is 4140 people, whereas the medium-risk area has 18461 people, and the low-risk area has 7740 people, making a total of 30341 people (19% of the total population).

DISCUSSION

The issue of preparedness in disaster resilience is of great importance both globally and locally. It was seen that the studies conducted on these issues for Turkey are mostly for the Marmara Region and particularly for Istanbul. However, for any scientific study to reach the relevant administrative units and for the respective measures to be implemented can be faster in medium and small-sized cities compared to those in metropolitan cities. Therefore, the selected study area is Niğde, a medium-sized Central Anatolian city for which no such study has been prepared before.

With this study, a dataset and approach has been developed that can be obtained and get results easily while also minimizing the financial and time cost. Vulnerable areas on the settlement can be found with spatial analyses done on protection and risk factors. Owing to this information, it is necessary to define intervention areas and priorities, especially, the density distribution of the urban population is a guide in this regard. Identification of vulnerable areas with high population density and high risk, and prioritizing the intervention will reduce damage before a possible disaster. For developing countries such as Turkey, these interventions will ensure that the moral losses experienced in the disasters are reduced as much as possible, while also guiding the authorities ensure a feasible use of the financial means.

The resilient city concept is a very detailed and multicomponent approach, and by means of this study, the current vulnerability of the city has been evaluated only on the basis of its built physical aspect. The analyses have shown that the area vulnerable to earthquake constitute a small percentage of the total study area for the province of Niğde, which is a medium-sized city located in a low-risk earthquake zone. However, the population that is likely to be affected is approximately one-fifth of the total population because these areas are located in the city center and densely populated areas. This, in this respect, indicates the importance of intervention and early prevention.

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