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Behavior Measurement Of Resilience Capacity Of Yazd Citizens In Seismic Activity Conditions Of The Taft Fault

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Abstract

The United Nations, in its MCR2030 project, has underlined the necessity of making the world's cities resilient against natural disasters by 2030. In this study, the resilience capacity of the Yazd citizens was measured in the event of a possible earthquake caused by the Taft fault, as large as 6.2 on the Richter scale, in the natural hazard management system (NHMS) and the geographic information system (GIS). First, a resilience zoning map was prepared using analytical geotechnical information in five homogeneous classes of Yazd city (A to E). Earthquake damages and losses in Yazd city were estimated through three stages: 1) calculating the peak ground acceleration (PGA), 2) estimating earthquake damage to buildings and vital lifelines, and 3) estimating earthquake losses. Next, the resilience of the neighborhoods was classified using the five-point Likert scale. The results showed that the highest resilience belongs to categories E, A, D, C, and B, in the order of their appearance. In the second part, the resilience of the Yazd citizens was measured by preparing and distributing a questionnaire and analyzing it with SPSS software. The analysis results showed that only neighborhood E was lower than the average resilience. The neighborhoods of this class are the outskirts of the city in the northwest and northeast of Yazd city. In the final stage of resilience measurement of the Yazd city and citizens, the resilience of the neighborhoods, from the highest to the lowest, was classified as follows: E, A, C, D, and B. Based on the obtained results, the resilience of neighborhoods E, A, and C was higher than 3 on average.

Keywords: *Behavior measurement; Resilience of Yazd citizens; Taft fault; Loss and damage estimation; Earthquake.*

1. Introduction

Iran is one of the major earthquake-prone countries in the world that has suffered many losses and casualties from earthquakes. Central Iran has a high seismic hazard potential due to the existence of old and large fault structures (Berberian, 1979). Yazd province, located in this structural block, has experienced devastating earthquakes throughout its history. The presence of seismically active faults with high seismic power around Yazd city has increased its seismic potential. Taft fault is one of the main faults of the Yazd block in the west bank of central Iran. This fault is one of the most important active faults in the city of Yazd. The fault is 30 km long and is located at a distance of 11 km south of the city of Yazd. However, considering the length of the Hamaneh fault, the total length of the Taft fault will be 90 km. This fault zone is located in the Taft region, the west and southwest of Yazd. With a dextral strike-slip mechanism, the Taft fault system has separated aqueducts, rock formations, and Quaternary alluvial fans along the fault direction. Evidence of this [1]separation exists along the Taft fault on Triassic rock units

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(840 m long), Quaternary alluviums (20 m long), and aqueducts (8 m long) (Javidfakhr, 2019). This fault has an east-west strike from the north of Taft to the central parts, wherein it has changed its direction toward the northwest. The continuation of the Taft fault toward the east has been covered by alluvial deposits and made invisible. On both sides of this fault, especially the northern part, the rock units have been severely faulted and displaced by this fault (Aramshian, 2016). Examining this fault system reveals three main classes: Taft Hamaneh, Mil Sefid, and Zardoshti. The two fault classes of Taft-Hamaneh and Mil Sefid are very similar structurally. In the Taft-Hamaneh fault zone, the fractal density indicates maturity and relative growth of the same size. Based on the fractal density, the Mil Sefid fault zone has a large surface area and less maturity. Zardoshti fault zone has a fractal dimension and a large surface area. This area is immature and growing. Also, it seems that the activity of this fault zone has led to numerous branches and deformation migrating toward the southeastern edge of the region next to the central Iranian subcontinent. Accordingly, these geodynamic conditions are very important in the Taft region’s structural analysis, seismotectonic, and strain division (Hajialibeigi et al., 2018). In its most critical state, this fault has the potential to generate a 6.2 Richter earthquake (Ambraseys and Melville, 1982). In this respect, an earthquake with a magnitude of 5 to 6 Richter in rural areas and 6 to 7 Richter in urban areas will be very catastrophic (Jafari et al., 2022). Hence, it is necessary to examine the resilience of the Yazd and its citizens based on this seismic force. In addition, examining the resilience of the roads in Yazd neighborhoods has shown that the new neighborhoods are in better condition than the old ones. This superiority can be attributed to the factors such as wider roads, better urban planning indicators, more suitable building features, more suitable green and open space, more favorable neighborhood and regional population density, and less closed degree compared to old and historical neighborhoods (Ghadirzadeh, 2017). The experience of past earthquakes has shown that the occurrence of a moderate earthquake in cities with low resilience results in significant damages and casualties along with numerous urban problems. The most important problems of urban management in case of such earthquakes include non-uniformed distribution of damage in different parts of the city, unfavorable conditions of urban development (e.g., the dispersion of dilapidation fabric and the lack of strength of buildings), the telephone and Internet outage, and lack of an integrated rescue management system and rescue groups. Although the damages, losses, and crises caused by an earthquake cannot be eliminated entirely, they can be reduced to a tolerable and acceptable level by considering the readiness level of the cities. In this respect, analyzing the results of city and citizen resilience assessment helps identify strengths and weaknesses of the system resilience cycle of the cities. The mutual influence of human (behavior) and natural (physical) factors is particularly important in evaluating cities’ resilience against natural hazards. Also, paying attention to the level of vulnerability to natural crises, awareness gained by experiences, personal feelings, religious beliefs, social dynamics, and individual behaviors plays an important role in using cities’ potential to face and respond appropriately to natural hazards.

Measuring the resilience behavior of citizens allows for detecting the extent of their participatory attitude in increasing multilateral cooperation, social innovation in facing crises such as earthquakes, and enhancing the city’s resilience capacity and the urban system’s citizens (Mahajan et al., 2022). In other words, local connections and citizens belonging to the neighborhood help them respond and recover from disasters to increase community resilience (Spialek and Houston, 2018). Identifying the city's and citizens' resilience against earthquakes shows the crisis degree to expect in the event of an earthquake. This achievement will lead to

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the improvement of crisis management and the possibility of identifying appropriate solutions to mitigate earthquake losses and casualties.

In the following, we describe some of the previous studies that are in line with the present study.

Bagheri Maragheh et al. (2022) evaluated the resilience of Shirvan city in the face of an earthquake. These authors calculated the weight of 26 criteria by Super Decision software with the help of 30 experts from the four following aspects: 1) Economical (i.e., land value, household income, and savings for crisis), 2) Physical (i.e., age of the building, type of materials, quality of the building, number of floors, area of parts, building density, grading, distance from the fault, user compatibility, distance from the road network, distance from the fuel station, distance from sensitive centers, distance from the water line, access to open space, access to relief and treatment centers), 3) Social (i.e., participation and solidarity of people, support of government and financial institutions, literacy, and the presence of voluntary), and 5) Institutional aid groups (i.e., planning of government institutions, saving in times of crisis, preparation of institutions). Then, they checked the city's resilience using a geographic information system (GIS), Expert Choice software, and the Analytic Network Process (ANP); one of the most complex multi-criteria decision-making methods. The results showed that of 26 neighborhoods, only 5 were in a suitable resilience state. In other words, 65% of the city was in an unsuitable resilience state. Most of these areas are located in the city's central area, where the buildings are old, the quality of buildings is low, the population density is high, and there is dilapidated urban fabric and structures.

Rajaee et al. (2021) conducted a spatial analysis of urban resilience against earthquakes in one district of Tehran city. They evaluated urban resilience with documentary and field methods and household questionnaire analysis by combining subjective and objective indicators in 4 infrastructural, social, economic, and institutional dimensions. These authors used SPSS software for statistical analysis and ArcGIS software for spatial analysis. According to their results, the dilapidated buildings and high-rise construction in the neighborhoods (which increase population density) and lack of green space are among the factors lowering the neighborhood resilience.

Nikpour et al. (2021) evaluated the resilience of Noorabad Mamsani (Fars Province, Iran) against natural disasters (earthquakes). They stated that vulnerability level against unpredictable events (e.g., earthquakes) could be reduced, resilience could be increased, and recovery time could be shortened using comprehensive knowledge of the event and its effects. They also demonstrated the role of the main institutions, managers, and urban planners in the design of the urban body. Their results showed a significant difference between the main indicators of the research, including 1) institutional (institutional performance, institutional platform, institutional relations, and institutional resilience), 2) physical (access, open space, service quality, and physical resilience), 3) economic (damage compensation, amount and severity of damage, ability to return to suitable conditions, and economic resilience), and 4) social (awareness, skill, attitude, knowledge, social capital, and social resilience). In terms of social, institutional, and physical resilience, the city was in a favorable state, while it was unfavorable from an economic perspective. The SPSS analyses revealed a statistically significant difference in terms of resilience aspects of different city areas.

Ma et al. (2021) investigated community resilience and residents' disaster preparedness in China's seismic areas. To this end, they surveyed selected residents from those affected by the earthquake in four Chinese cities. In the end, they concluded that greater social communication support would lead to a higher potential for society's changeability and manage disaster management. As a result, overall preparedness against disasters is higher, and resilience is higher. In a society where residents' communication is closer, the knowledge exchange will increase, leading to more efficient disaster management. The closer the society is to the idea that it will not suffer from disasters and experience sustainable life, the less the effect of understanding the disaster risk will be on them. Also, governments should create reliable networks to inform citizens to neutralize rumors and help them be resilient in crisis by providing them with accurate and correct information.

Panday et al. (2021) studied the role of social capital in disaster resilience in remote communities after the 2015 Nepal earthquake. They stated that social capital is a key element in improving disaster resilience. The barriers were removed immediately after the earthquake thanks to the high levels of bonding and bridging social capital among residents (self-help at the local level), collective actions, and assistance to rescue and support affected people. However, after the arrival of foreign aid, these bonds were lost. Those with socio-cultural status or political connections benefited in the long-term relief and reconstruction stages.

On the other hand, women and the elderly were deprived of resources and marginalized, jeopardizing their long-term recovery from natural disasters and resilience. Also, bonding social capital cannot benefit remote villages compared to villages closer to the road because residents cannot communicate and convey their needs to the government. Resilience programs must ensure that bonding capital only serves the elite and recognize that pre-existing inequalities (e.g., socio-cultural, gender, and geographic) may create unequal social capital between individuals and communities after a disaster, thereby lowering disaster resilience. Socio-cultural inequalities (i.e., inequalities caused by weak bonding relationships in families, gender inequalities, and remoteness of villages) further weaken remote communities' social capital and resilience. Disaster relief programs should target women and the elderly to increase their resilience. Accordingly, more attention should be paid to these groups, and they should be connected with the members of the society to aid them in suffering less damage during the reconstruction phase and benefit from support. They also emphasized the effect of existing non-governmental organizations and non-governmental organizations in the relief process. After the temporal dimension of social capital as the key to response in disasters, the following actions might be useful in the reconstruction phase: the collective rescue of the community and relief measures immediately after the earthquake, exclusion of marginalized groups after the arrival of external aid, and social capital. However, these factors may grow inequalities.

Bao et al. (2021) investigated multi-disaster scenario methods and emergency management for urban resilience by integrating test data, simulation, and field data. According to these authors, due to the frequent occurrence of multiple disasters worldwide in recent years, the analysis of effective multi-disaster scenarios is essential in disaster relief and emergency management. Response methods for various individual hazards have already been reviewed and formulated. However, disaster scenario reviews are rarely systematically applied to the entire development and response process of multiple. More specifically, due to the complex effects of different risks, it is difficult to prevent, control, and deal with multi-hazard disasters in real emergency management only by considering the dynamics of a single hazard and traditional response methods. The occurrence of multi-hazard disasters means that coupling more than one hazard in specific spatio-temporal regions leads to increased structural and systematic damage. Therefore, experimental technologies of small-scale measurement, field measurement, and prototype simulations can be used to investigate causal mechanisms and develop multi-risk evolution dynamics. In this regard, new technologies of artificial intelligence (AI) and Internet of Things (IoT) technology can be used to improve multi-disaster scenarios and emergency management for urban resilience. For instance, they mentioned multi-risk disasters in the 2011 earthquake off the coast of Japan's Tohoku in the Pacific Ocean, which caused a cascading tsunami and a nuclear meltdown in a power plant and radiation leakage. In this example, there is a need for an effective scenario that examines and manages all risk factors together. Various fast multiscale simulation studies have been conducted for multi-disaster events to investigate disaster evolution and development based on multiscale experimental data and theoretical analysis. Data-driven methods and multiple hazard visualization tools have been developed. For example, the US Hazards-Multi-Hazard System (HAZUS-MH) developed by the US

Federal Emergency Management Agency (FEMA) is a complete GIS-based expert system. It integrates detailed data on the built environment and damage functions to provide estimates of losses from earthquakes, floods, storms, and other hazards.

In line with the objectives of the MCR2030 project, this article aims to measure the resilience of the Yazd citizens under seismic activity conditions of the Taft fault. To this end, the resilience of Yazd and its citizens is evaluated in the spatial dimension of Yazd city, the social dimension of the residents, and the infrastructure dimension of its buildings. By measuring the resilience of the urban system as a whole, which includes a network of intertwined components, the physical part (structures, buildings, and the open environment of the city), the social part (citizen society), and the ongoing interactions between these parts, this study will help increase its resilience based on the 10-fold principles of the MCR2030 project. This research, in addition to using the typical components in resilience measurement, aims to extend the resilience assessment from qualitative and quantitative to a wider range of neglected components. For this purpose, we use geotechnical information such as the severity of damage (structural and non-structural components) and losses caused by earthquakes. It is noteworthy that, in evaluating the urban system as a whole and its partial components in two qualitative and quantitative modes, the qualitative approach relies on personal judgment and perception.

On the other hand, the quantitative approach objectively compares the various components of the urban system and offers a general numerical metric comparison for the global community (Rus et al., 2018). The present study aimed to quantify the collected information for quantitative metric analysis. Since some of the collected quantitative and numerical information was not available or accessible, all qualitative information is based on the Likert spectrum. Accordingly, based on expert opinions, studies, and software classification, these data were classified into five numerical categories ranging from “very bad” to very good” (from 1 to 5).

2. Methodology

The current research includes two parts: 1) losses and damage estimation and 2) resilience measurement using statistical analysis.

In this first part, losses and damages caused by the seismic activity of a 6.2 Richter earthquake on the Taft fault were estimated in 3 steps. In the first step, the seismic parameters caused by a 6.2 Richter earthquake in the eastern part of the Taft fault were calculated for Yazd city through simulation. In the second step, possible damages caused by earthquakes to buildings and the main lifelines of Yazd city were estimated by measuring the behavior of buildings against earthquakes. In the third step, the possible loss caused by the earthquake was calculated through modeling.

Step 1: Calculating the peak ground acceleration (PGA)

Despite the importance of ground motion parameters (e.g., duration, frequency, displacement, and speed), in most cases, the PGA is the main parameter to estimate earthquake damage to structures. PGA is calculated as a function of earthquake magnitude, fault type, epicenter distance, and construction effects (Graizer and Kalkan, 2016). The Natural Hazards Management System (NHMS) helps developing countries make cities more resilient based on the 10-fold principles of the MCR2030 campaign. This organization is responsible for improving the process of making cities resilient in Iran through its web-based software and application, earthquake damage estimation for emergency operation centers (EOC), identification of possible scenarios in the most critical conditions possible, the right attitude toward changing risks, and a special focus on vulnerable populations and resilience for different parts of the city. NHMS estimates the PGA on the seismic bedrock through the Ground Motion Prediction Equations (GMPEs) (Kangi, 2015). This comprehensive model is based on 2,583 accelerogram records related to 47 medium and large earthquakes in the world (8 earthquakes from Iran and Turkey) by the USGS institute.

In the PGA estimation model, the ground motion range is fitted as response functions by specific packages (filters) one after the other. This model can be used for shallow crust earthquakes in Iran (except for the Makran mountain range) based on earthquake characteristics, fault type, geophysical characteristics, and other local parameters (Graizer and Kalkan, 2016). In this process, the structure of earthquake energy reduction equations inside the earth's crust is the same for the whole country. Also, for each part of the geographical area covered by the system, the seismic coefficient of the area will vary by the shear wave speed of the earth's crust and other effective parameters. In the first stage, the seismic zoning model of Tavakoli and Ghafory-Ashtiany (1999) is used to choose the regional coefficient. In this research, the PGA zoning map of Yazd city was prepared using the NHMS data. In this process, the set of ground motion attenuation equations used in the PGA estimation model are applied to calculate the PGA on the seismic bedrock. In these equations, the earthquake magnitude, the fault type, the PGA reduction rate with the distance from the epicenter, and the regional correction factor are considered. Next, the accuracy of the model for estimating the PGA was verified by comparing the simulation results of Iran's past earthquakes in the framework of NHMS with the records of accelerometer results related to the same earthquake. This set of information includes characteristics of earthquakes (i.e., magnitude, focal depth, location of the epicenter, and fault's seismic mechanism), accelerometer records of the earthquakes, and geophysical characteristics of accelerometer stations.

Step 2: Estimating earthquake damage to buildings

In general, estimating earthquake damage to buildings is directly related to three categories of basic parameters. The first category includes the parameters of strong ground motion (e.g., PGA), which varies based on the earthquake's magnitude, the place of occurrence, the geotechnical characteristics of the building, and the model of energy dissipation in the earth's crust. The second category of building seismic parameters (roof displacement spectrum, SD; and roof acceleration spectrum, Sa) is related to the technical specifications of structural components. The third category includes earthquake damage estimation methods. Using a structural failure curve is among the most important methods for estimating earthquake damage to buildings. In this regard, the use of the HAZUS failure curve is among the most common and state-of-the-art methods for estimating earthquake damage to buildings based on GIS data. In this method, certain behavior is considered for the vulnerability estimation of each category of building. Also, the behavior measurement of buildings at different levels of acceleration caused by earthquakes is predicted probabilistically. The ability of this method to estimate the seismic damage of buildings has been proven in several earthquake-prone countries of the world, such as America, Japan, Taiwan, and Turkey. The HAZUS project and associated software development were initiated by the US Federal Emergency Management Agency (FEMA) in the early 1990s to enhance preparedness levels for natural disaster events. The software provided by this project allows for identifying the expected crisis level for different scenarios of natural events before they occur. To this end, it uses analysis of risks caused by different events to buildings, facilities, and vital lifelines. During the HAZUS project evolution, it has always been tried to improve the methods of earthquake damage analysis and software optimization through rapid earthquake damage assessment in new versions based on the existing facts. The evolution of this software over three decades has turned it into a practical method in natural crisis management (Schneider et al., 2006). HAZUS is effective for mitigation, restoration, preparedness for disaster response, identification of possible damages and casualties, reduction or minimization of damages and casualties, and risk assessment in planning at all stages of crisis management and resilience-making.

Step 3: Estimating the earthquake losses

Using the GEFE model, earthquake loss was estimated through lognormal distribution. The number of losses caused by earthquakes was estimated using the model offered by the USGS for estimating the losses of world earthquakes (Jaiswal et al., 2010). This model was implemented in the framework of the NHMS, which showed the possibility of quick estimation of earthquake losses in urban areas (Kangi, 2015). For this purpose, residential areas were divided into squares with the same area based on the density of geotechnical boreholes. Then, the PGA value for the center of each square was calculated based on a PGA-based simulation. Afterward, using 4 main parameters (i.e., the population living in each square, the PGA, the earthquake loss rate at this level of the PGA, and the strength of the buildings), the amount of expected loss in each square was estimated. Finally, the total losses of the squares were calculated, and the loss distribution map was drawn in the city. Accordingly, the city of Yazd was divided into squares of 200 m × 200 m, and the losses caused by a 6.2 Richter earthquake in the eastern part of the Taft fault were calculated.

In the last stage of the first part, we need to integrate the map of human casualties and the percentage of possible damage into a single map. Since experts have considered the importance of casualties more than damage, the layer of casualties compared to damage was assigned a weight of 1.4. To integrate these layers, we made the scale of these two maps the same. Therefore, the prepared loss percentage map was converted into very good (No. 5), average (No. 3), and very bad (No. 1) categories. Eventually, the Sum operator (algebraic addition) was used to overlap these two maps.

In the second part of studying the resilience of the Yazd citizens in the event of this possible earthquake, the resilience of the citizens living in Yazd city was determined via statistical analysis based on its existing capacities. The collected information was expressed using descriptive statistics and analyzed using inferential statistics. This research uses statistical tests such as the Kolmogorov-Smirnov test, independent t-test, Mann-Whitney, one-way analysis of variance (ANOVA), Kruskal-Wallis, and Spearman's correlation coefficient. SPSS statistical software version 25.00 was used to investigate and answer the research questions in this study. The information collected by the statistical analysis questionnaire was converted into a map in the GIS environment. The citizenship (household) questionnaire was prepared and distributed for the study area using the map of urban areas of Yazd municipality and through quantitative and qualitative methods.

The following factors were considered in a quantitative method and the form factor (physically known). The municipal map defines the boundaries of urban neighborhoods that are homogeneous in terms of social and economic characteristics (Consulting Engineers Arse, 2007). The form factor includes the spatial distribution pattern of the building, the physical characteristics of the building, the life of the building, the materials used, the height, the physical quality, the spatial distribution pattern of the buildings, the route of urban streets, urban land use, identification of the villages integrated into the main body of the city, the characteristic physical elements, natural complications and phenomena, quantitative characteristics of residential units, and stages of physical development of the city over time (Poorahmad et al., 2005).

In the qualitative method, based on process factors (spatial-physical), the results showed the importance of distributing questionnaires among 30 urban experts (i.e., municipal experts, social affairs experts of the governorate, and technical professors) and conducting interviews and people's behavior in the form of spatial boundaries (e.g., cultural behavior, the sense of connection between the residents and their sense of belonging to the neighborhood). Some questions were set to determine the degree of internal homogeneity (i.e., social, economic, and cultural) of the neighborhood, the sense of belonging, and the cohesion degree of the residents. In this study, 41 separable neighborhoods were identified and then classified into five homogeneous classes (with their conditions ranging from "very good" to "very bad"). These five areas were investigated with a combined method (quantitative, qualitative, and urban form) and in terms of social, economic, and urban context factors. These factors were determined according to the availability of numerical data or the possibility of classifying them qualitatively based on the experts' opinions. These experts were 30 urban, social, and economic management experts who were chosen from among the available experts based on Cochran's formula. The investigated factors were prepared to identify homogeneous classes and determine the resilience of neighborhoods under three layers of information in social, economic, and urban context dimensions.

In the social dimension, the sub-layers include population density, education, age, access to relief, management, welfare, special centers, indigenous and non-indigenous residence type, and marginalization. In the economic dimension, the sub-layers include the index of employment and gross capital. In the dimension of the urban fabric, the sub-layers include the dilapidation percentage, building density, vulnerability, and technical and non-technical factors. Based on the research needs, these sub-layers were classified into five categories, ranging from very good to very bad. The dilapidation percentage of the urban fabric is based on three indicators of Smallness (blocks with more than 50% of the plaque area less than 200 m^2), instability (blocks with more than 50% of unstable buildings and no reinforcement system), and impermeability (blocks with more than 50% of passages being less than 6 m wide) (Zangi Abadi et al., 2011). Eventually, a vulnerability map was prepared using 15 criteria, including land use, area, geometric shape, location of the piece, population density, structure, age, quality, occupation level, number of stories, building density, fire fighting, open spaces, and rescue centers and passage. According to the research needs, all sub-layers were classified into five categories, from very good to very bad. Then, each layer was classified into five categories. Factors whose numerical information was not available were converted from qualitative to quantitative information using the opinion of experts. This quantification was done using a five-point Likert scale (ranging from 1 = very bad to 5 = very good). First, using the opinion of experts and the conditions of the studied area, the order of importance of the dimensions (the most and least important with an impact factor of 3 and 1, respectively) was determined. This order was the social dimension, the urban context, and the economic dimension. Then, analyses were performed using a simple incremental weighting scoring method based on weighted averages. In this method, they are unscaled or scaled accordingly to compare the layers and effective factors (Gilvari et al., 2014).

Finally, all the layers were classified into five categories (score one to five). Each dimension was scored based on the order of importance. Next, according to the expert's opinion, a normalized weight was assigned to each layer. Eq. (1) presents the method of reaching each dimension's main weight (S). This equation is based on the algebraic addition operation for multiplying the score of the Ith option according to the jth attribute (Sij) and the normalized weight (Wi).

$$S= \Sigma(Sij) \times (Wi) \qquad (1)$$

In each dimension, the weight of the main dimension is determined by algebraic sum operation (SUM) and then averaging. Next, this weight is assigned to each neighborhood. The historical and dilapidated fabric of the city was placed in "very bad" homogeneous classes. This classification is due to factors including inappropriateness of communication routes (narrow alleys and lack of vehicle access for crisis management, sending goods, equipment, and relief) and infrastructural issues (deterioration of the urban facilities network, the complexity of the distribution mainlines, especially the gas, water, and electricity networks due to the specific texture and condition of the alleys). Accordingly, crisis resilience management becomes difficult for relief, service, and operation units. Historical areas, with a complex system of social, economic, ecological relations, etc., are highly vulnerable to crises such as earthquakes. However, it is possible to investigate and enhance resilience using modern methods and software such as GIS before, during, and after the earthquake (Giovinazzi et al., 2021). The neighborhoods located in the historical context, dilapidated fabric, and outskirts of the city fall into the "very bad" classification. These neighborhoods are Nasrabadi, Sajjadiyeh, Amirabad, Charkhab, Maryamabad, Fahadan, Seyed ol-Shohada, Mahdiabad, Khairabad, and Eishabad (Heidari Noshahr and Nazarian. 2011).

In the next step, using Cochran’s formula and based on the population of Yazd, 384 household questionnaires were distributed as a sample number in the statistical population, homogeneous classes, and clusters. This distribution is randomly clustered in the five homogenized classes based on the population percentage of a single homogeneous class (A to E) compared to the total percentage of the sample respondents (384 people) in the statistical population. The city of Yazd had a population of 596,894 in 2021. The number of questionnaires in the neighborhoods in Classes A to E was 34 (9% of the total), 81 (21%), 154 (40%), 61 (16%), and 54 (14%), respectively. The researcher performed a field visit to complete the information and check the areas. The items of the citizenship (household) questionnaire are self-expressed and related to the level of awareness, knowledge, skill, attitude, etc., of the person being questioned. These items were designed to determine the personal and family resilience level of the participants in a natural crisis (e.g., an earthquake). The items of the citizenship questionnaire were designed by reviewing the relevant studies, the opinions of experts and technical professors, and the region's characteristics. The information layers examined through the household citizenship questionnaire included 1) human-social (i.e., awareness, knowledge, skill, attitude, social capital (comfort and satisfaction), and sense of collaboration and trust), 2) economic dimensions (i.e., financial capacity to compensate for damages), family’s financial ability to return to the conditions before the family crisis (gross domestic product; GDP), 3) the severity of physical damage to the family’s property (employment and economic well-being of the family)), and 4) administrative-institutional (the platform of institutions, the relations of institutions and the performance of institutions). All the obtained information was quantified through the five-point Likert scale. First, the information was generally described using descriptive statistics methods. Then, the obtained data were analyzed using inferential statistics. To this end, we used statistical tests such as the Kolmogorov-Smirnov test, independent t-test, Mann-Whitney, one-way analysis of variance (ANOVA), and Kruskal-Wallis and Spearman’s correlation coefficient. Research questions were analyzed using SPSS statistical software version 25. In the descriptive statistics section, demographic characteristics (i.e., gender, age, education level, neighborhood, length of residence in Yazd city, and length of residence in the neighborhood) were analyzed with descriptive statistical methods, such as frequency tables and statistical charts, to understand the research population (i.e., 384 participants). After examining the descriptive statistics, inferential statistics were used to extract the relationship between factors such as gender, age, education, neighborhood, length of residence in Yazd city, and length of residence in the neighborhood with different layers of resilience. In the end, the correlation between different layers of resilience was measured.

In the behavior measurement questionnaire, the resilience of human-social dimension layers includes awareness, knowledge, skill, attitude, social capital (comfort and satisfaction and sense of cooperation), and trust. Next, we examined the relationship between the homogeneous neighborhood of Yazd city and human-social resilience, the homogeneity of the variance of the human-social resilience of people from different neighborhoods, and the normality of their data distribution. Regarding the validity of both assumptions for all groups, the analyses were performed using one-way ANOVA. The results showed that the place of residence in the neighborhood significantly affects human-social resilience. Pairwise Tukey's comparison of the human-social resilience of people in different neighborhoods revealed that the average human-social resilience of people living in Classes A, B, and C is significantly higher than those living in Classes D and E.

In the behavior measurement questionnaire, the resilience of the layers of the economic dimension includes the family’s financial capacity to compensate for the damage, the financial ability to return to the family’s pre-crisis conditions (gross family production), and the severity of the damage to the family’s property (employment and economic well-being of the family).

In examining the relationship between the homogeneous neighborhood of Yazd city and economic resilience, the Kruskal Wallis method was used for analysis due to the non-existence of the assumption of normality of data distribution of economic resilience of people in Classes C, D, and E. The results showed that the place of residence in the neighborhood does not significantly affect economic resilience.

In the resilience behavior measurement questionnaire, the administrative-institutional dimension layers include the institutions' foundation, the institutions' relations, and the institutions' performance. In investigating the relationship between the homogeneous neighborhoods of Yazd city and institutional administrative resilience, the Kruskal Wallis method was used for analysis since the default distribution of administrative-institutional resilience data of individuals is not established in Classes C, D, and E. It was found that the neighborhood significantly affects institutional management resilience. Pairwise Mann-Whitney comparison of institutional management resilience of individuals with different neighborhood classes showed that people's average institutional management resilience in Classes E and D is not significantly different. However, the institutional resilience of people in Classes E and D was more than in other neighborhoods. The average institutional management resilience of people in Class A is significantly higher than the average institutional management resilience of people in Class B.

The results showed a significant positive correlation between different layers. In other words, human-social, economic, and institutional management resilience have a positive and statistically significant relationship. Finally, the method of averaging was used to investigate the overall resilience in each dimension of five homogeneous classes of Yazd.

In the final stage of the first part of the research, the resilience zoning map of Yazd city was prepared using geotechnical information and the NHMS system (casualty estimation and estimating the percentage of structural and non-structural damage caused by seismic activity up to 6.2 Richter in Taft fault). In the second part, the resilience behavior map of Yazd citizens in the event of a possible earthquake was prepared for five homogeneous Classes (social-human, economic, and management-institutional dimensions) in the ArcGIS environment based on the percentage of the area of the pixels inside the homogeneous Classes. Finally, it was integrated as a unified map using the algebraic SUM operator.

3. Discussion and conclusion

3.1. Phase I: Earthquake loss and damage estimation

Earthquake damages and losses in Yazd city were estimated in 3 stages, including the calculation of the PGA, the estimation of earthquake damage to buildings and vital lifelines, and the estimation of earthquake losses.

3.1.1. PGA calculation

PGA zoning map of Yazd city was prepared through simulation in the event of a 6.2 Richter earthquake in the eastern part of the Taft fault, with a distance of 15 km from the center of Yazd to a depth of 8 km. For this purpose, first, the earthquake PGA on the seismic bedrock is calculated using the PGA estimation model. Then, considering the effect of soil intensification, the PGA zoning map of Yazd city under the conditions of this earthquake was drawn (Fig. 1).

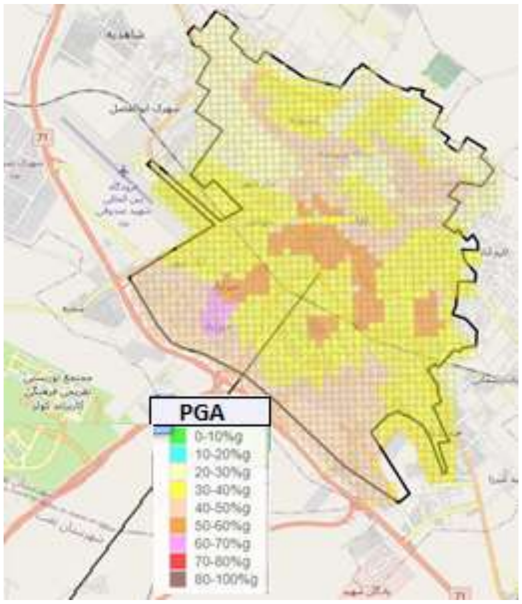

Fig. 1. Peak Ground Acceleration (PGA) zoning map of Yazd city in the event of a 6.2 Richter earthquake in Taft fault (NHMS system)

Fig. 1 shows soil intensification amplification in the study area, processed using DEEPSOIL software based on seismic geotechnical data of 24 boreholes in Yazd city. As can be seen, the Khairabad neighborhood has a maximum PGA of 60 to 70%.

3.1.2. Estimating earthquake damage to buildings

In the present research, damage caused by the earthquake in Yazd city was estimated at two levels: measuring the behavior of important buildings and zoning the possible damage in the city. For this purpose, the failure curve of buildings and vital lifelines was extracted through the HAZUS project. Next, they were implemented and processed in the framework of the natural hazards management system. Fig. 2 shows the behavior measurement of important buildings, including the Yazd Municipal building, against a 6.2 Richter earthquake in the eastern part of the Taft fault.

Fig. 2. Behavior measurement of important buildings against a 6.2 Richter earthquake in the eastern part of the Taft fault (NHMS system)

As shown in Fig. 2, The seismic activity of the Taft fault with a 6.2 Richter earthquake, with a focal distance of 16.99 km, a PGA of 32.5 will lead to a roof displacement spectrum of 3.17, and roof acceleration spectrum of 51.07 and experience negligible damage of structural components and moderate damage of non-structural components in Yazd Central Municipality Building (located in Bagh Meli Square).

Fig. 3 presents the zoning map of the damage estimation of buildings in Yazd city in the event of a 6.2 Richter earthquake on the eastern part of the Taft fault, obtained in the NHMS and analyzed in ArcGIS environment.

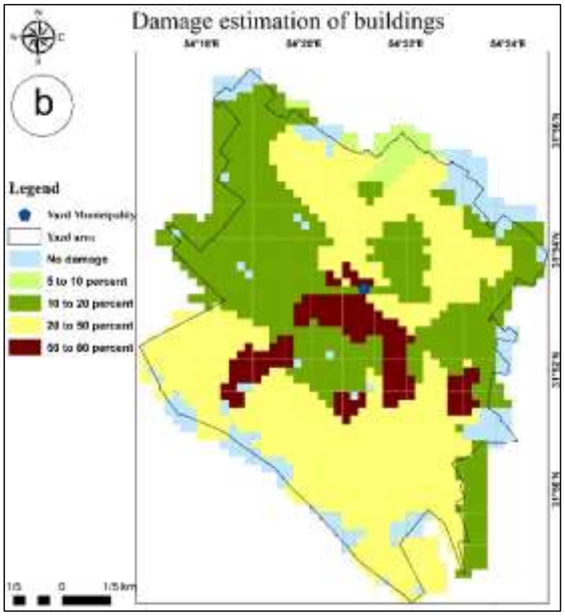

Fig. 3. Zoning map for damage estimation of buildings in Yazd city in the event of a 6.2 Richter earthquake in the eastern part of the Taft fault

As shown in Fig. 3, the map of damage to buildings caused by the 6.2 Richter Taft earthquake in areas with historical and dilapidation fabric (especially dilapidation and old fabric) is more than in other areas (50-80% damage), while it will be even without damage in the outskirts.

3.1.3. Estimation of earthquake losses

Fig. 4 illustrates the zoning map of the casualties of Yazd city in the event of a 6.2 Richter earthquake in the eastern part of the Taft fault.

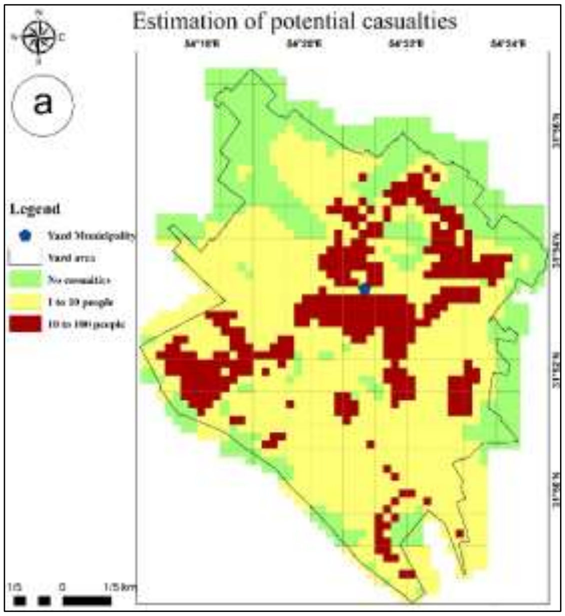

Fig. 4. Zoning map of casualties in Yazd city in the event of a 6.2 Richter earthquake in the eastern part of the Taft fault

As shown in Fig. 4, the casualties of this event were estimated with 67% probability, equivalent to 11,469 people. The highest casualties can be expected in the central and western parts of the city (i.e., Khairabad and Azadshahr).

At the end of the first part, the combined map (human casualties + probable damage percentage) was classified according to the five categories of the Likert spectrum (Fig. 5a). Then, loss and damage level was determined based on the total area of the pixels in each homogeneous class and averaging the final resilience of each neighborhood. This map was also classified into five categories, from very good (5) to very bad (1), based on the Likert scale (Fig. 5b).

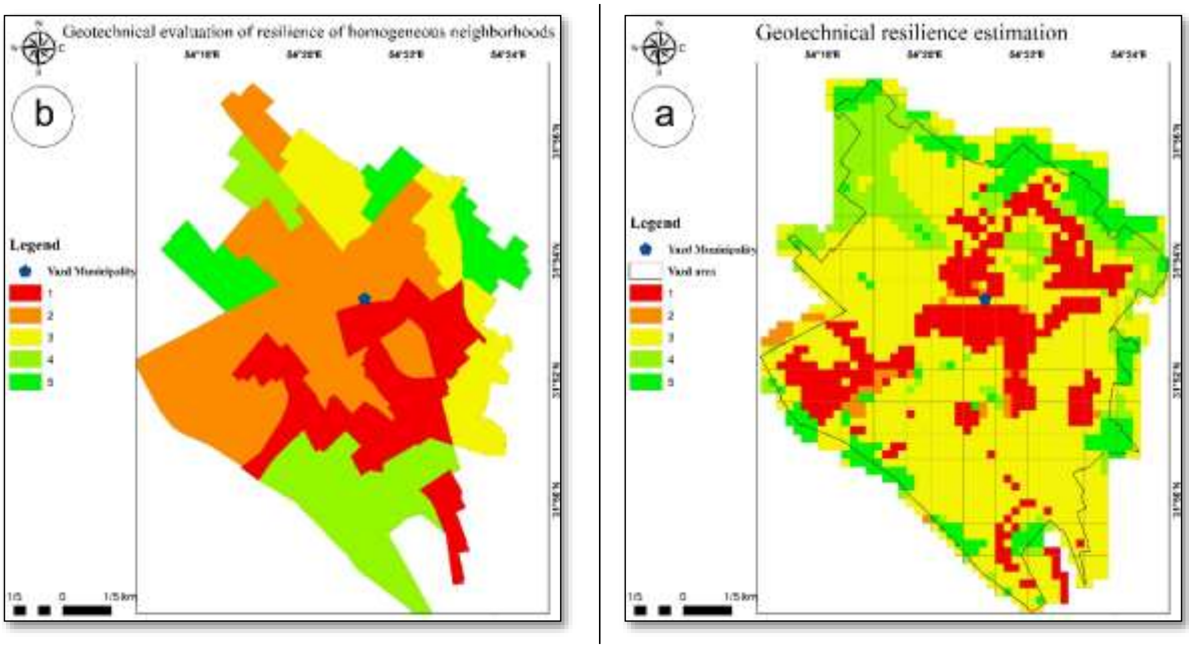

Fig. 5. a) Yazd city resilience zoning map using geotechnical information integrated by the NHMS and ArcGIS and b) Yazd city resilience zoning map using geotechnical information integrated by the NHMS and ArcGIS in five homogeneous classes of Yazd

Fig. 5a presents the resilience zoning of Yazd city using GIS information and geotechnical information from the NHMS system. As can be seen, the Yazd municipality building is located in the bad resilience class. According to Fig. 5b, Class E neighborhoods are in very good resilience status (5), Class A neighborhoods are in good status (4), Class D neighborhoods are in average status (3), Class C neighborhoods are in Bad condition (2), and Class B neighborhoods are in very bad condition (1).

Fig. 5b indicates the resilience zoning map of Yazd city using GIS information and geotechnical information from the NHMS system. As can be observed, the Yazd municipality building is located in the bad resilience class. According to this map, Class E neighborhoods are in very good resilience status (5), Class A neighborhoods are in good status (4), Class D neighborhoods are in average status (3), Class C neighborhoods are in Bad condition (2), and Class B neighborhoods are in very bad condition (1).

3.2. Measurement of resilience behavior of citizens (households) of Yazd city against earthquake

In this section, the resilience capacity of the Yazd citizens against earthquakes was measured. Fig. 6a shows the population density map (people per hectare) of Yazd city in 5 Classes, from very low to very high density. Also, Fig. 6b presents the education index map of Yazd city in 5 categories from very low to very high density.

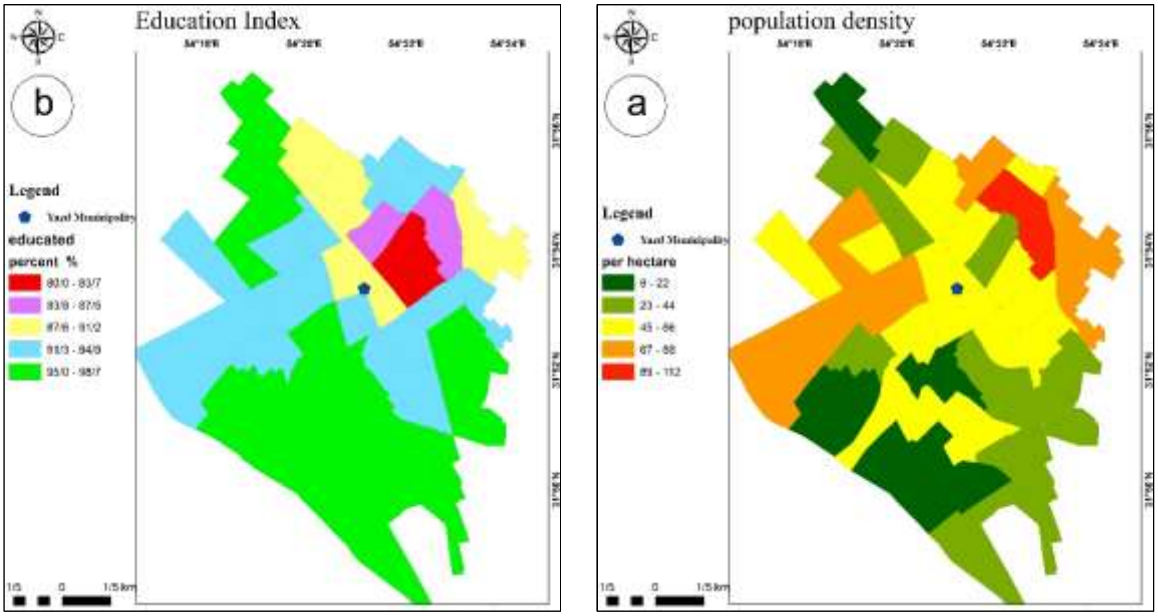

Fig. 6. (a) Population density map (people per hectare) of Yazd city and (b) Yazd education index map

As shown in Fig. 6a, of 41 neighborhoods of Yazd city, the neighborhoods in the north and southwest of Yazd city have very high population densities (89 to 112 people per hectare). Also, Fig. 6b shows that neighborhoods in the south, southeast, and northwest of Yazd city have very high education (95 and 98.7%).

Fig. 7 exhibits the employment and unemployment rates of Yazd citizens in five classes, from very low (red) to very high (dark green).

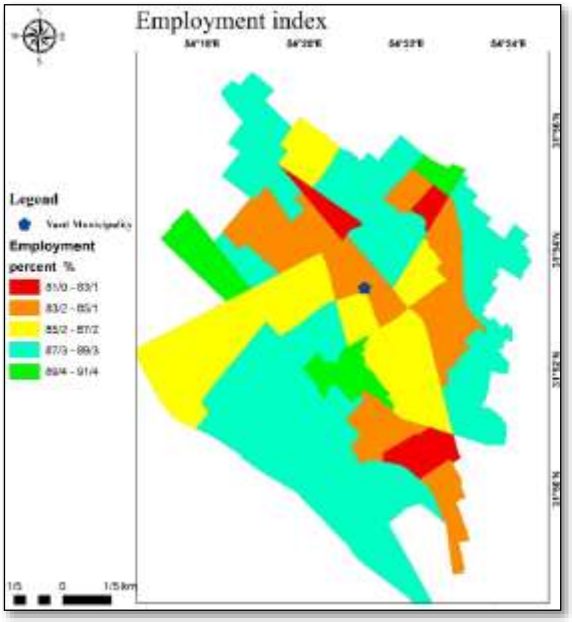

Fig. 7. Employment percentage map of Yazd citizens

As shown in Fig. 7, of 41 neighborhoods of Yazd city, those in the center, east, and west of the city have a very high percentage of employed people (89.4 and 91.4%).

Fig. 8a shows the percentage of dilapidation in Yazd city in five classes, from a very low to a very high percentage. Fig. 8b shows the building density map of Yazd city in five classes, from very low building density to very high building density percentage. Finally, Fig. 8c depicts the vulnerability index map of Yazd city in five classes, from very low to very high.

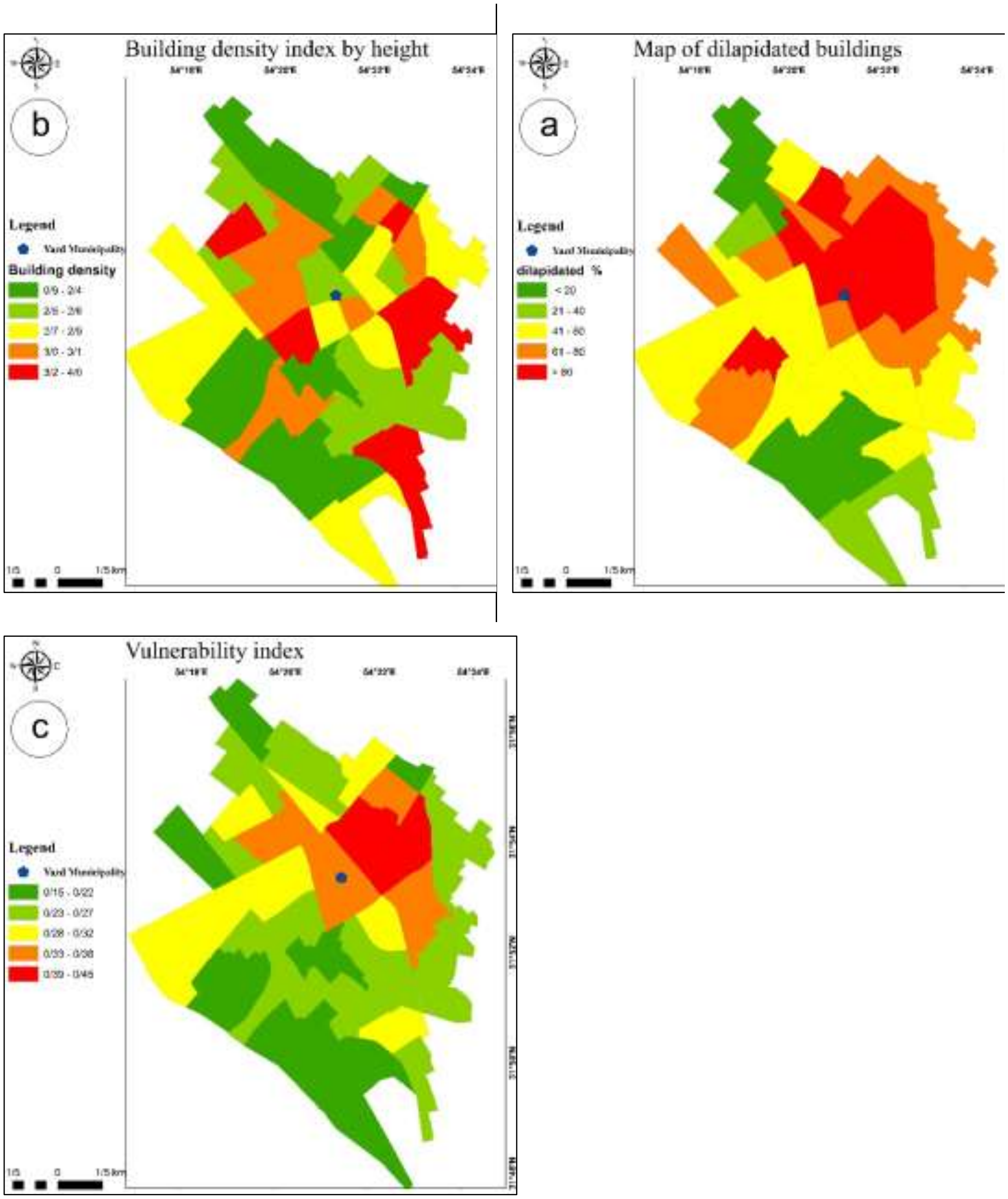

Fig. 8. Maps of the city (a) erosion percentage, (b) building density map, and (c) vulnerability index

As shown in Fig. 8a, of the 41 neighborhoods of Yazd city, those in the historical, old, and dilapidated neighborhoods have a very high percentage of worn-out fabric (80%). According to Fig. 8b, of these 41 neighborhoods, those in the south, center, east, north, and northeast of the city have a very high building density (3.2 to 4). Also, Fig. 8c shows that neighborhoods with very high vulnerability index percentages (39 to 45%) are located in the city's historical context. Furthermore, the city's vulnerability map shows that Khajeh Khadhar, Lab-e Khandaq, Gazergah, Yaqoubi, and Takht-e Ostad are the most vulnerable neighborhoods (Abui Ashkazari et al., 2012). Overall, the vulnerability map showed that 50% of the area of Yazd has a higher-than-average vulnerability in a probable earthquake.

Next, the 41 neighborhoods of Yazd city were classified into five homogeneous classes. Here, the number of respondents in each neighborhood was determined based on the percentage of the population of a single homogeneous neighborhood (Classes A to E) compared to the total percentage of the sample respondents (384 people) in the statistical population (the studied area of Yazd city with a population of 596,894 in 2021). The number of questionnaires in neighborhoods of Class A was 34 (about 9% of the total), while it was 81 (21%) in Class B, 154 (40%) in Class C, 61 (16%) in class D, and 54 (14%) in Class E (Fig. 9).

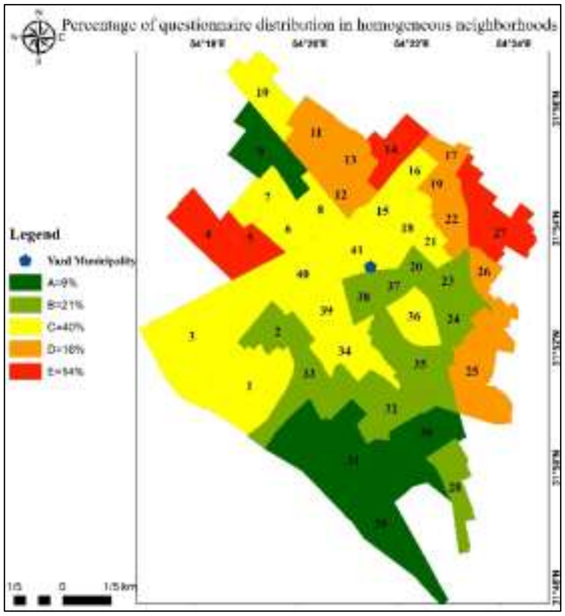

Fig. 9. Classification maps based on five homogeneous classes in Yazd and the percentage of questionnaire distribution in each homogeneous class

As shown in Fig. 9, the questionnaire distribution share in a clustered and random manner in selected homogenous neighborhoods in Class C is about 40%, which is more than in other neighborhoods. This distribution was selected based on the percentage of the residents in the neighborhoods.

Then, the citizenship questionnaire was analyzed using the SPSS software. Examining the frequency distribution of gender revealed that almost half of the sample were men and half were women. Also, 51.6% of the respondents were in the age group of 35 to 65 years, 38.8% had a bachelor’s education, 55.5% lived in Yazd for more than 20 years, and 30.5% lived in their current neighborhood for 10 to 20 years.

Table 1 presents the results of human-social resilience of the five homogeneous classes of Yazd using the method of averaging.

Table 1. Average of human-social resilience of five homogeneous classes of Yazd

Class	Number of respondents	Awareness	Skill	Knowledge	Attitude	Social capital	Trust	Average resilience of the human-social dimension
A	34	3.05	2.67	3.08	3.83	3.07	3.46	3.14

B	81	2.68	2.4	2.82	3.84	3.2	3.89	3.14
C	154	2.75	2.59	2.87	3.68	3.26	3.69	3.14
D	61	2.27	2.22	2.52	3.32	3.32	3.85	2.92
E	54	2.13	1.96	2.45	3.2	3.51	3.81	2.85
Total	3.84	2.58	2.37	2.75	3.57	3.27	3.74	3.08

Table 1 shows that the resilience of all five classes of Yazd city in the human-social dimension was higher than the average (i.e., 3). As shown in Table 2, the economic resilience of the homogeneous classes of Yazd was investigated using the method of averaging.

Table 2. The average economic resilience of the five homogeneous classes of Yazd

Neighborhood	Number of respondents	Damage degree	Financial capacity	Return ability	Average resilience of economic dimension
A	34	3.04	2.63	2.62	2.76
B	81	2.99	2.41	2.39	2.6
C	154	3.06	2.56	2.49	2.7
D	61	3.31	2.37	2.15	2.61
E	54	3.32	2.22	2.05	2.53
Total	384	3.14	2.44	2.34	2.64

According to Table 2, he resilience of all five classes of Yazd city in the economic dimension was lower than the average (i.e., 3). Also, as shown in Table 3, the administrative-institutional resilience of the five homogeneous classes of Yazd was investigated using the method of averaging.

Table 3. Average administrative-institutional resilience of the five homogeneous classes of Yazd

Class	Number of respondents	Performance of institutions	Relation of institutions	Background of institutions	Average administrative-institutional resilience
A	34	3.21	3.04	2.52	2.92
B	81	2.56	2.76	2.12	2.48
C	154	2.82	2.85	2.31	2.66
D	61	1.82	2.7	1.56	2.03
E	54	1.76	2.65	1.66	2.02
Total	384	2.43	2.8	2.03	2.42

Table 3 indicates that the resilience of all five classes of Yazd city in the administrative-institutional dimension was lower than the average (3), except Class B (close to average). Table 4 shows the average resilience of the five homogenous classes of Yazd city according to the three dimensions of human-social, economic, and administrative-institutional.

Table 4. Average resilience of five homogeneous classes in Yazd

Neighborhood	Number respondents	Average resilience of human-social dimension	Average resilience of economic dimension	Average resilience of administrative-institutional dimension	Neighbor's average resilience
A	34	3.19	2.76	2.92	2.96
B	81	3.14	2.6	2.48	2.74
C	154	3.14	2.7	2.66	2.83
D	61	2.92	2.61	2.03	2.52
E	54	2.85	2.53	2.02	2.47
Total	384	3.08	2.64	2.42	2.7

According to Table 4, the most resilient classes were A, C, B, D, and E, in the order of their appearance. The final average of the resilience of Yazd city identified through the citizenship (household) questionnaire was 2.7, which was lower than the average (3). As a result, the resilience of Yazd city in terms of citizenship falls in the bad to average class.

Fig. 10 shows the map of the resilience behavior of the Yazd citizens based on five homogeneous classes.

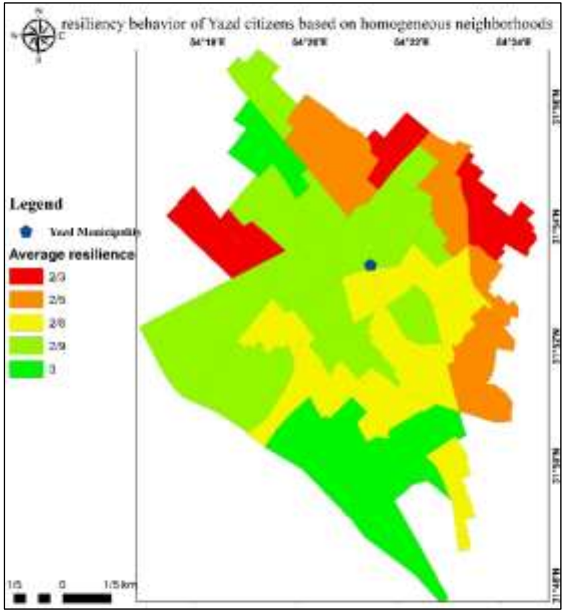

Fig. 10. Map of resilience behavior of Yazd citizens based on homogeneous neighborhood classes

According to the resilience behavior map of the Yazd citizens city based on homogeneous neighborhood classification (Fig. 10), from very high to very low resilience, the neighborhoods fall into the following classes: A, C, B, D, and E. More specifically, Class A neighborhoods are in very good resilience, Class C has good resilience, Class B has medium resilience, Class D has bad resilience, and Class E has very bad resilience. The resilience number of (C), (B), (D), and (E) class neighborhoods was lower than the average resilience (3). Only Class A neighborhoods had an average resilience. Class E neighborhoods (with the lowest level of resilience) include the outskirt areas in the northwest and northeast of Yazd city. These neighborhoods are worse than others in terms of the citizens' resilient behavior. Based on this analysis, citizens should be considered in these special planning areas to manage the resilience to the possible earthquake crisis.

In the final map, the resilience of the city and Yazd citizens was determined by dividing the homogeneous classes based on the Likert spectrum from very good (5) to very bad (1) (Fig. 11).

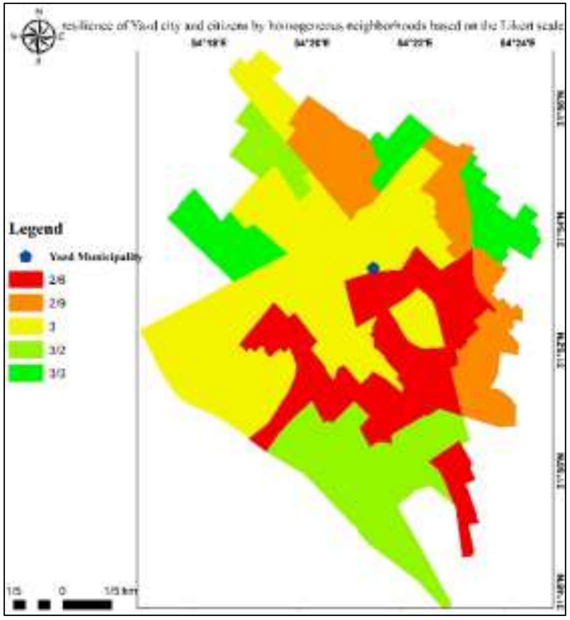

Fig. 11. Final map for measuring the resilience of Yazd city and citizens by homogeneous classes based on the Likert scale

Based on the final map of measuring the resilience of the city and Yazd citizens in the seismic activity of the Taft fault up to a 6.2 Richter earthquake, neighborhood Classes E, A, C, D, and B have very high to very low resilience, in the order of their appearance. The resilience of neighborhoods in Classes E, A, and C was higher than the average (3). In addition, according to the five-point Likert scale, neighborhoods in Class E are in very good resilience (5), Class A in good resilience (4), Class C in medium resilience (3), Class D in bad resilience (2), and Class B in very bad resilience (1). Also, the central municipal building of Yazd city was chosen as a sample building and was examined and visited. The analysis showed that the overall resilience of the structural and non-structural components of this building, along with the resilience of the citizens living in this area, has an average resilience. Therefore, it is necessary to consider the issue of empowering citizens and city managers in future planning, along with improving the resilience of the structure and urban infrastructure network affected by and affecting it.

4. Conclusion

Based on the information obtained from the produced maps, the major results of this study can be outlined as follows:

1. Class E neighborhoods in the map combining losses and damage percentage (geotechnical survey) have had very good resilience. Behavior measurement of citizens' resilience in the event of a possible earthquake based on five homogenous neighborhoods (social-human, economic, and management-institutional dimensions) showed that this neighborhood class was lower than the average resilience (very bad). In the final combination resilience map of the study area, the resilience of the city and citizens was very good.

2. Class A neighborhoods in the loss and damage percentage map (geotechnical survey) had good resilience. Measuring citizens' resilience in the event of a possible earthquake based on five homogenous neighborhood classes showed that this class is more resilient than the average (very good). In the final combination resilience map of the study area, this class was in good condition in terms of the city and citizens' resilience.
3. Class C neighborhoods in the loss and damage percentage map (geotechnical survey) had bad resilience. The behavior measurement of citizens' resilience in the event of a possible earthquake based on five homogenous neighborhoods showed that this class was lower (good) than the average resilience. In the final combination resilience map of the study area, this class was in good condition in terms of the city and citizens' resilience.
4. Class D neighborhoods in the map combining the percentage of losses and damage (geotechnical survey) had moderate resilience. The behavior measurement of citizens' resilience in the event of a possible 6.2 Richter earthquake for five homogenous neighborhood classes showed that the resilience was lower than the average (bad) for this class. In the final combination resilience map of the study area, this class was in bad condition in terms of the city and citizens' resilience.
5. Class D neighborhoods in the map combining the percentage of losses and damage (geotechnical survey) had very bad resilience. The behavior measurement of citizens' resilience in the event of a possible 6.2 Richter earthquake for five homogenous neighborhood classes showed that the resilience was lower than the lower (moderate) for this class. In the final combination resilience map of the study area, this class was in very bad condition in terms of the city and citizens' resilience.

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