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A measurement of community seismic resilience in sub-city districts of Mashhad, Iran

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Communities that are more resilient to seismic hazards are often able to retain their functions in a time of crisis and experience faster recovery. This study develops a holistic approach for assessing community seismic resilience in thirteen sub-city districts of Mashhad. Three resilience properties (robustness, resourcefulness, and redundancy) are matched with six community resilience dimensions to construct a Community Seismic Resilience Index (CSRI). The aim of CSRI is to quantify districts' coping capacities to mitigate the adverse impacts of a hazard, and their adaptive capacities to recover in an efficient and timely manner. The geography of CSRI suggests that there is a division between the east and the west of the city that builds a pattern of spatially segregated resilience to seismic hazards. Based on the findings, urban policies should be directed toward enhancing the robustness of communities and building redundancy into institutional/managerial systems in order to build more resilient communities.

Keywords: Community Seismic Resilience Index; Mashhad (Iran); coping capacity; adaptive capacity; composite index

1. Introduction

Seismic hazards, due to significant losses and abrupt disruptions in community functions and services, have become a high priority in the field of disaster risk reduction (Bruneau *et al*. 2003; Renschler *et al*. 2010). It is generally accepted that rapid urbanization and distribution of population in at-risk areas, particularly in developing countries, are root causes of large-scale economic and human losses due to earthquakes (Gu *et al*. 2015). Despite the great interest in the growth of mitigation and response capacity of communities, building a more resilient community is one of the main priorities of governments, stakeholders, and researchers. Whilst there is a strong recognition in the literature about the prominence of promoting a resilient community, there is no general agreement upon a conceptual definition and standard mechanism for operationalizing the term (Birkmann 2006; Cutter *et al*. 2008; Ostadtaghizadeh *et al*. 2016; Asadzadeh *et al*. 2017). The need for developing a numerical means of resilience assessment has resulted in building several frameworks with a set of metrics in order to measure/compare community resilience in response to different types of hazards over time. Each framework is backed up by a theory to conceptualize resilience and offers a methodology for operationalizing the concept. Today, scholars and decision

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makers agree that the concept of community resilience is very context-specific, and any assessment attempts should take into account the type, location and scale of the hazard (Kafle 2012; Moore, Chandra, and Feeney 2013; Ostadtaghizadeh *et al*. 2016). While the increasing number of community resilience case studies have matured the index-based research process, there are a limited number of frameworks developed by local research on developing countries to reflect local needs and conditions (see Sharifi 2016).

The purpose of this article is to construct a theoretically-driven index to measure community seismic resilience in sub-city districts of Mashhad, Iran. The Community Seismic Resilience Index (CSRI) could be adopted as a baseline to compare districts and to monitor their changes over time by a set of indicators in socio-demographic, economic, environmental, organizational/managerial, physical/infrastructure, and cultural/community competence dimensions. The article starts by reviewing the concept of 'seismic resilience' and then proposes a relevant framework for building indices related to seismic hazard and applicable to the community under study. In order to build robust and reliable indices, varied published works addressing metrics for community seismic resilience are analyzed and the most relevant, robust, and quantifiable indicators are selected and integrated into the study framework. Subsequently, each sub-city district in Mashhad is assessed based on equally weighted indicators, and, the results are visualized to compare different communities' capacities in times of hardship and to determine the logic behind the spatial dispersion of resiliency in the city. Finally, potential implications for planning, policy, and decision-making are identified.

1.1. Context of seismic resilience in Iran

Being located on the Alpine-Himalayan belt, Iran is geographically and geologically highly vulnerable to earthquake hazards. Based on the seismic hazard zoning map, more than two-thirds of the total land area in Iran is prone to high seismic risks (Asagharimoghadam 1999). According to a survey by the Global Assessment Report on Disaster Risk Reduction (2015), in Iran earthquakes have caused 92.1% of total disaster-related mortality and 30.4% of national economic loss between 1990 and 2014. The Rudbar-Manjil earthquake (1990), South-Khorasan earthquake (1997), Bam earthquake (2003), Lorestan earthquake (2006), Azarbaijan earthquake (2013), and Kermanshah earthquake (2017) are among the most destructive earthquakes that caused long-standing socio-economic disruption. The government of Iran has taken several disaster risk reduction initiatives in line with international frameworks, including the 1990s framework for International Decade for Natural Disaster Reduction, 2005–2015 Hyogo Framework for Action, and 2015–2030 Sendai Framework for Disaster Risk Reduction. These initiatives include compilation of earthquake safety codes for buildings (Standard-2800 and Iran's School Safety Program Act), inclusion of risk management in 5-year National Development Plans, inter-sectoral coordination between institutions involved in disaster management, and several revisions of disaster management legislation. Despite the efforts to establish a comprehensive and integrated disaster risk management scheme in Iran, several shortcomings are still present: the overly centralized disaster management system (Tierney *et al*. 2005), multiplicity of decision makers and units involved in disaster management (Bahrainy 2003), excessive attention to post-disaster relief/recovery and negligence of pre-disaster mitigation (Bahrainy 2003; Safari, Seyedin, and Jahangiri 2019), and weak community participation in disaster risk management (Tierney *et al.* 2005; Amini Hosseini and Izadkhah 2020). Experiences obtained from various hazard-related situations in Iran reveal that the concept of disaster management should not be regarded as only post-disaster operations and measures. Rather, the need for disaster risk reduction, hazard mitigation and enhancement of community resilience should be the most significant tasks of the disaster management system. Few studies have been conducted to conceptualize and operationalize community resilience in Iran. In Asadzadeh, Kotter, and Zebardast's (2015) quantitative study, community resilience was measured in 22 sub-city districts of Tehran by adopting Cutter, Burton, and Emrich's (2010) multi-hazard BRIC framework. A brilliant qualitative study by Ostadtaghizadeh *et al.* (2016) offers a context-based approach to community resilience in which the authors develop conceptual and working definitions of community resilience, as well as its dimensions and attributes for the Iranian context. To enhance community resilience at local level, Bastaminia *et al.* (2018) assess seismic resilience capabilities of community in the city of Yasuj (Iran) through a quantitative evaluation of resilience dimensions and components using the scorecard method (questioners in Likert format). Finally, a recent work by Atrachali *et al.* (2019) adopts both quantitative and qualitative methods to assess urban seismic resilience in a few sample areas of Tehran and Kish Island. These studies have contributed to the current discussion on the role of context specificity in conceptualization and operationalization of community resilience.

For several reasons, this article complements previous research conducted in the field of community resilience in Iran: 1) this work is the first attempt to conceptualize and measure community seismic resilience in Mashhad; 2) the methodology and the procedure for indicator selection have been tailored to address resilience to 'seismic' hazards; 3) the theoretical framework and indicators of this research can be applied to other large cities in Iran for comparative purposes.

1.2. Context of seismic hazard in Mashhad

Mashhad, the center of Khorasan-e Razavi Province, is located in the northeast of Iran along the valley of Kashafrud-River between the two mountain chains of Binaloud and Hezarmasjed (Figure 1). The city is located on alluvium beds in a high intensity seismic zone with 0.3–0.35 *g* maximum acceleration (Akbari *et al.* 2011). Four fault lines surround the metropolitan area of Mashhad, including Kashaf-Rud fault in NW-SE direction parallel to the Kopet-Dag mountain in north of Mashhad, Tous fault which is a branch of Kashaf-Rud fault in NW-SE direction, Sangbast-Shandiz fault which is a significant fault in Binaloud mountain in the south of Mashhad, and the southern fault of Mashhad-Chenaran (Figure 2). The first three faults are outside the administrative boundary of Mashhad, whilst a part of the southern fault (Mashhad-Chenaran) covers districts 7, 8, and 9 of the municipality of Mashhad.

The natural geography of Mashhad metropolitan region has given a linear pattern to the city's growth, which today covers a total built-up area of 328 square kilometers divided into 13 local administrative districts run by a mayor. Historically, the city gained its reputation for the shrine of Imam Reza – the eighth Muslim Shia Imam – which is a complex of historic religious monuments covering an area of 598,657 square meters in the heart of Mashhad. Due to its immense religious importance the city has gained population and experienced physical growth in past decades; Mashhad has grown from 667,700 inhabitants in 1976 to 3 million in 2016 obtaining second

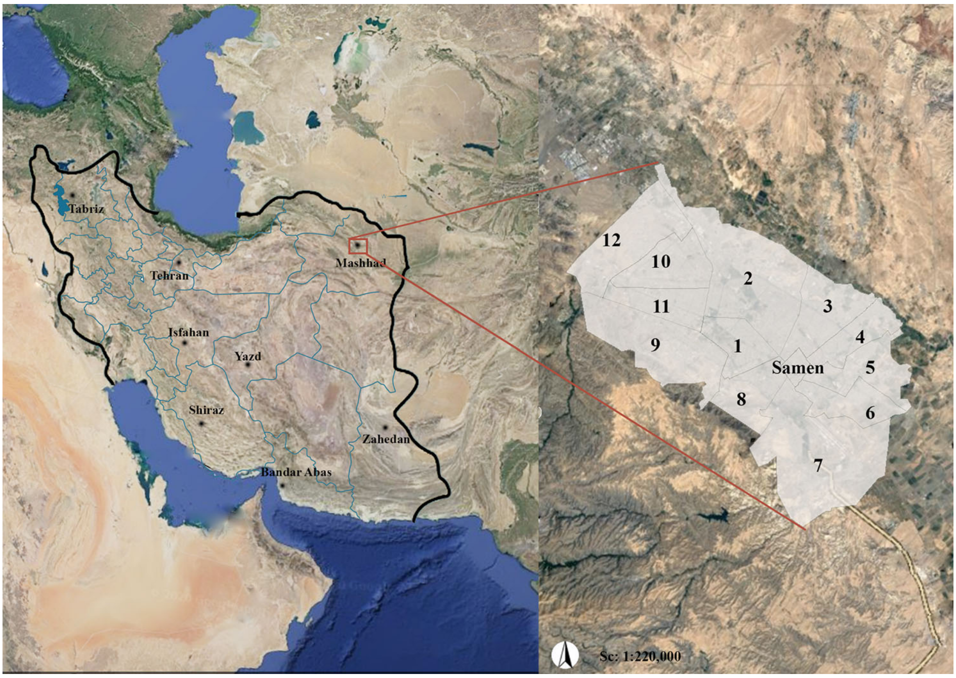

Figure 1. Municipality of Mashhad and its 13 sub-districts.

place after Tehran in terms of population size (Municipality of Mashhad 2017). Fast demographic changes have been accompanied by uneven growth and development of the city characterized by high population density, deteriorated urban fabric, violation of construction codes, and environmental pollution which have made the city vulnerable to potential future seismic hazards. According to historical records, the city has witnessed several severe earthquakes among which the most destructive was reported on 30 July 1673 and resulted in destruction of two-thirds of the city and 4,000 deaths (Ambraseys and Melville 1982, 51). In 2006, approximately 275 microtremors and earthquakes occurred in Mashhad metropolitan region, of which three were above 4.4 Richter. The latest shock occurred on 5 April 2017 in *Sefid Sang* (southern margin of Mashhad Valley) with 6.1 magnitude and several aftershocks for two days which halted many activities in Mashhad. After the 2017 earthquake, the provincial branch of the National Crisis Management initiated several technical programs, including detailed mapping of fault lines and amending construction codes in adjacent area of the faults. However, the main focus of the provincial working group has largely remained on technical safety issues and less attention has been paid to seismic resilience at community level.

2. Methodology

This study adopts composite indices for quantifying seismic resilience at community level by integrating a set of sound, robust and measurable variables that contribute to community seismic resilience in Mashhad. The community in this article is composed of households and individuals in a shared geographical/administrative boundary (i.e.

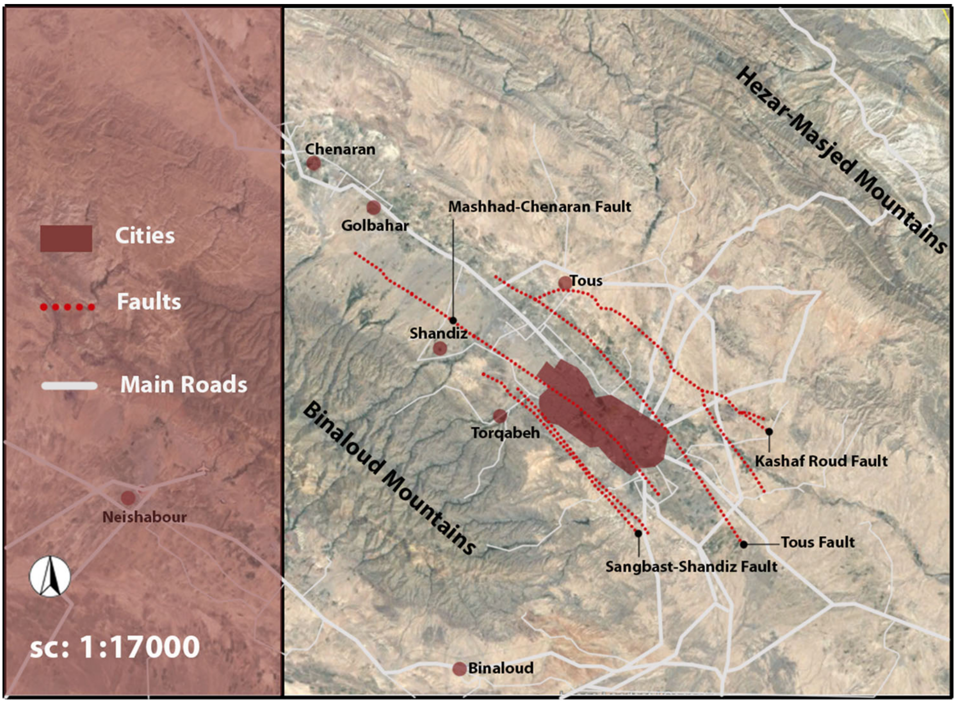

Figure 2. The location of fault-lines around Mashhad metropolitan region.

sub-city districts) who are linked by dynamic socio-economic interactions. The choice of sub-city districts as the spatial unit of analysis is because sub-city districts are spatial/administrative units that are run by districts' municipalities for which a wide range of data are available. Therefore, our sample is comprised of 13 sub-city districts in the municipality of Mashhad.[1]

Assessment of community resilience by using composite indicators has become an acceptable method in disaster management and academic discourses in the past two decades (see, e.g. Mayunga 2009; Cutter, Burton, and Emrich 2010; Cutter, Ash, and Emrich 2014; Ainuddin and Routray 2012; Burton 2015; Cutter, Ash, and Emrich 2014; Asadzadeh, Kotter, and Zebardast 2015; Yoon, Kang, and Brody 2016). Despite the critics (see Greco *et al*. 2019), several justifications are often cited for adopting composite indices: 1) composite indices can "summarize complex, multi-dimensional realities with a view to support decision-makers," (Nardo *et al*. 2008, 13); 2) as the mathematical combination of several single indicators, indices quantify complex phenomena and turn them into easily understandable subjects, (Cutter, Burton, and Emrich 2010); 3) composite indices are also considered a useful tool for decision-makers to compare the performance of systems over time and to better allocate resources (Yoon, Kang, and Brody 2016).

In order to build composite indices, several steps are taken (see also Nardo *et al*. 2008; Cutter, Burton, and Emrich 2010):

1. Conceptual definitions and developing a theoretical framework for measuring community seismic resilience in Mashhad;

2. Identifying and selecting sound, relatable, and available indicators based on literature review and expert assessment;
3. Transforming raw data into comparable scales (percentage, per capita, density function);
4. Application of multivariate/correlation analysis;
5. Normalizing data (min-max rescaling equation);
6. Aggregation of indicators' scores and calculating the resilience score for each sub-city district of Mashhad;
7. Visualization of results.

The data selection for this study is based on the 2015 municipal census, the 2015 GIS map of Mashhad, the report on Identification of Social Harms and Anomalies in Urban Neighborhoods of Mashhad (2015), the report of Public Satisfaction Toward the Municipality and City Council of Mashhad (2015), and the report on Registered Public Requests at the Municipal Public Relation Center. The reason for choosing only secondary data is the availability of accurate, reliable, and comprehensive data at the district level once every five years (public census) which facilitates the monitoring of community seismic resilience over time and comparison of one district to another[2].

3. Resilience to seismic hazards

Resilience is subject to potential conflictions and can have utterly contradictory meanings in different disciplines (Alexander 2013). In the context of natural hazards, resilience is defined as an inherent attribute of a system that comprises the ability to cope with a hazard, mitigate, adapt, recover and regain functionality from the impacts of a hazard in an efficient and timely manner (Cutter *et al*. 2008; Norris *et al*. 2008; Mayunga 2009; O'Connell *et al*. 2015; United Nations Office for Disaster Risk Reduction 2017). Although this is a fully-fledged definition of resilience to natural hazards, recent studies suggest that any treatment of the concept should take into account features of gender, context, and culture (Kafle 2012; Ostadtaghizadeh *et al*. 2015, 2016; Nordberg 2018). In the field of seismic hazards, resilience is often defined with reference to a system's functional performance (Bruneau *et al*. 2003). Therefore, resilience can be defined as the capacity of a system to perform its functions without significant changes during and after an earthquake, and the ability to return to an acceptable level of functioning as rapidly and efficiently as possible (Bruneau *et al*. 2003). This can be achieved by enhancing the robustness of a system's critical infrastructures (Bruneau *et al*. 2003; Bruneau and Reinhorn 2007; Cimellaro, Reinhorn, and Bruneau 2010; Arcidiacono *et al*. 2012; Dong *et al*. 2019), developing mitigation measures to reduce earthquake risks (Davidson *et al*. 1998; Comerio 2004), and promoting recovery strategies to return to an acceptable level of functioning as rapidly as possible (Miles and Chang 2006; Zhang, Alipour, and Coronel 2018).

3.1. Community seismic resilience

The concept of 'community resilience' raises the same contradictions and conflictions as the concept of resilience, due to its correlation with geographical scales and various meanings the term 'community' implies (Norris *et al*. 2008). Community is often defined as a place-based social system with a defined boundary and area of action for decision makers. A resilient community, as a working definition in this article, is a community that has the ability to cope with hazards, self-organize and recover from hardships with collective actions. The above definition includes two main components: coping capacity and adaptive capacity. Coping capacity refers to the ability of a community to use its available capital (financial, technical, human, community) to absorb, mitigate, and finally recover from the adverse impact of a hazard without significant impact on its function (Parsons *et al*. 2016). Therefore, coping capacity is a function of a system's inherent characteristics that has the potential to withstand harm. These characteristics are determined by physical, social, economic, and environmental factors that attenuate or amplify the hazard impacts on a community (United Nations Office for Disaster Risk Reduction 2005, 1). Adaptive capacity is a term that has more relevance in global change studies; however, its attributes can be extended to individuals, households, and communities to respond and recover from natural hazards. In the disaster risk management field, adaptive capacity is the during-event and post-event functions of a community which entail the ability "to adjust to change, moderate the effects and cope with disturbance." (Cutter *et al*. 2008, 600) Community's adaptive capacity is determined by institutional, management, social and economic arrangements and processes that enables the community to adjust to the inevitable impacts of a hazard through learning, adaptation and transformation (Norris *et al*. 2008; Parsons *et al*. 2016).

In this article, a community's seismic resilience is a concept that encompasses the interrelationship between a community's coping capacity to seismic hazard on the one hand, and its ability to respond, to absorb, and to recover hazard impacts on the other hand. Both coping capacity and adaptive capacity contribute to a community's resilience and can be applied to socio-demographic, economic, institutional/organizational, cultural/community competence, physical/infrastructure, and environmental systems.

4. Assessment framework for community seismic resilience

Community Disaster Resilience (CDR) frameworks are continually evolving as a result of growing changes in global dynamics and an increasing trend in the number of hazardous events. Parallel to theoretical concepts, many scholars have introduced frameworks to operationalize and measure CDR on different geographical scales (See Cutter (2016), Sharifi (2016), Asadzadeh *et al*. (2017), Almutairi, Mourshed, and Ameen (2020), and Nguyen and Akerkar (2020) for a complete review of community resilience frameworks). The comparison between different frameworks reveals the disparity in the way the concept is defined and measured in different contexts which results in "no universal procedure for operationalizing the community disaster resilience." (Asadzadeh *et al*. 2017, 148). Based on literature review and expert opinions, most CDR frameworks include social, economic, institutional/organizational, community competence, physical/infrastructure, and environmental dimensions as the main attributes of community resilience (Bruneau *et al*. 2003; Norris *et al*. 2008; Sherrieb, Norris, and Galea 2010; Cutter, Burton, and Emrich 2010; Burton 2015; Yoon, Kang, and Brody 2016; Ostadtaghizadeh *et al*. 2016; Parsons *et al*. 2016). Recently, literature on cross-country comparative studies of disaster resilience adds an often-neglected 'cultural' dimension to the list of resilience attributes (Ostadtaghizadeh *et al*. 2016).

In the last 20 years, the academic and policy making arena have witnessed a growing interest in conceptualizing and operationalizing 'seismic resilience' from

Table 1. Community seismic resilience frameworks.

Seismic resilience framework	Developer	Main dimensions and number of indicators	Unit of analysis	Methodology for framework development	Data source
Earthquake Disaster Risk Index (EDRI)	Davidson *et al.* 1998	Hazard (3), Exposure (3), Vulnerability (2), External Context (2), Emergency Response & Recovery Capacity (3)	Metropolitan area (comparative analysis of the major world cities)	Unclear	Secondary data from local, national and international statistics
System Diagram (A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities)	Bruneau *et al.* 2003	Technical, Organizational, Social, Economic	Critical infrastructures (lifelines, hospital systems, power plants, …)	Scenario-based seismic resilience assessment Quantitative assessment of resilience as degradation in system's robustness and required time to recovery	–
Multi-disciplinary Framework for Seismic Resilience	Verruci, Rossetto, and Twigg 2012	Planning and Land-use (5), Built-in Resilience (13), Continued Functionality (7), Resources (16), Social Cohesion (2)	Urban Area (Suggestions were made for evaluation of the 'Planning and Land use' indicators for the case of 1994 Northridge earthquake)	Literature review (System Diagram and EDRI)	Secondary data from census and Tax Assessor data/ Remote Sensing and GIS
Community Resilience Index (CRI)	Ainuddin and Routray 2012	Social (6), Economic (4), Institutional (3), physical (4)	Community (comparative study of two regions in Baluchistan, Pakistan)	Literature review mostly based on Cutter, Burton, and Emrich BRIC framework (2010)	Primary and secondary data including National Census and qualitative surveys

(*Continued*)

Table 1. (*Continued*).

Seismic resilience framework	Developer	Main dimensions and number of indicators	Unit of analysis	Methodology for framework development	Data source
Seismic Resilience Index (SRI)	Asadzadeh, Kotter, and Zebardast 2015	Built Environment & Social Dynamics (6), Urban Land-use & Dependent Population (4), Socio-cultural Capacity (3), Life Quality (4), Open Space (2), Social Capital (2), Emergency Infrastructure (3), Economic Structure (2)	Community (Municipal districts of Tehran, Iran)	BRIC framework combined with F'ANP model to construct SRI	Secondary data from municipal Census
Spatial variability of social vulnerability to seismic hazard	Frigerio *et al.* 2018	Age (4), Employment (4), Education (2), Anthropization (3), Residential Property (1), Ethnicity (1)	Country (social vulnerability of municipalities in Italy)	Literature review mostly based on Cutter, Boruff, and Shirley's Social Vulnerability Index (2003)	Secondary data from national Census
Seismic Resilience Assessment of Complex Urban Systems	Koren, Kilar, and Rus 2018	Quantitative modeling of an urban system by means of four main components (i.e. Buildings, Infrastructure, Community, and Open Space)	Urban scale	System diagram combined with Social Vulnerability Index to assess urban resilience at three time phases: preparedness, response, recovery	–

multidisciplinary perspectives. The first attempt in this area is attributed to Bruneau *et al*. (2003) for theorizing seismic resilience as characterized by four main resilience properties of an engineering system (known as 4Rs): Robustness, Redundancy, Resourcefulness, and Rapidity. Their framework integrates the 4Rs into four resilience dimensions (technical, organizational, social, and economic); each can be quantified to measure the seismic resilience of a system. In their model – known as System Diagram – Bruneau and colleagues focused on the system's functionality with special attention to critical infrastructures (power, pipelines, hospitals, and local emergency services) before and after the earthquake event. The degree of resilience is based on two factors: (1) the ability to resist the sudden external shocks (robustness) and (2) the ability to reduce the time required for recovery (rapidity). Bruneau *et al.*'s conceptual model of resilience has been expanded by several scholars in attempts to define metrics and measures for resilience assessment of lifelines (Cimellaro, Reinhorn, and Bruneau 2011; Ouyang, Dueñas-Osorio, and Min 2012), transportation systems (Vugrin *et al*. 2010; Arcidiacono *et al*. 2012; Kilanitis and Sextos 2019; Koc *et al*. 2020), and hospital networks (Bruneau and Reinhorn 2007; Yu *et al*. 2019; Shang, Wang, and Li 2020). Expanding the System Diagram model, Renschler *et al*. (2010) integrates physical/infrastructural assets of a system with its socio-economic-organizational aspects to develop multi-dimensional metrics for resilience assessment of communities at various spatial and temporal scales. The model – known as PEOPLES – addresses multiple hazards and contains seven dimensions (i.e. population and demographics, environmental/ecosystem, organized government services, physical infrastructure, lifestyle and community competence, economic development, and social–cultural capital) along with a set of subsystems and indicators to measure the potential performance of a community before and after the hazard event. Therefore, to measure community seismic resilience it is necessary to consider not only physical damage, environmental degradation, and economic loss, but also social, economic, cultural, and institutional factors that contribute to the overall resilience of a given community.

In the last 20 years, several frameworks for measuring community seismic resilience have been developed. Some of these frameworks, as illustrated in Table 1, have adopted composite indices and quantitative data to measure community seismic resilience at different geographical scales. Reviewing these frameworks, three points are worth highlighting: (1) in the past two decades the pure engineering-based approach to seismic resilience has gradually been integrated with the community-based approach to include socio-economic dynamics as well as institutional settings in assessment of a system's resilience to seismic hazards; (2) the trajectory also highlights a move from criteria-based assessment (see Cimellaro, Reinhorn, and Bruneau 2011; Arcidiacono *et al*. 2012; Yu *et al*. 2019) to holistic assessment of seismic resilience; and (3) most frameworks take into account the indicators relating to the coping capacity (i.e. robustness) of a system to seismic hazards and did not attempt to include adaptive capacity indicators.

This article adopts Bruneau *et al.*'s concept of "resilience properties" as a theoretical foundation to measure community seismic resilience in Mashhad's sub-city districts. The first resilience property, robustness, is considered as the coping capacity of a community, whilst redundancy and resourcefulness are linked to the adaptive capacity of a system in which alternative elements and resources (human, economic, managerial, community) increase a system's ability to adjust and re-organize in response to

Table 2. Community seismic resilience matrix – dimensions and definitions.

Community Seismic Resilience Dimensions (Based on literature review)	Community Seismic Resilience Property (3Rs) (Adopted from Bruneau *et al.* 2003)		
	Robustness (Coping Capacity)	Redundancy (Adaptive Capacity)	Resourcefulness (Adaptive Capacity)
Socio-demographic	(SR1) Social characteristics of a system that is either susceptible or resilient to external shocks (examples: age, education, ethnicity …)	(SR2) Alternative means for communication and mobilization of social/human resources to meet community needs (examples: multi-lingual ability, multiple university degrees, family ties, memberships …)	(SR3) Human resources necessary to restore community's critical functions (examples: highly skilled individuals, social welfare, NGOs …)
Economic	(EcR1) Economic characteristics of a system that reduce monetary loss and disruptions in business at the time of unexpected shocks (examples: wealth, know-how, insurance …)	(EcR2) Existence of alternative economic capacity and resources for the community (examples: multiple sources of income …)	(EcR3) Existence of financial/monetary resources necessary for restoring community's economic functions (examples: wealth, bank credits, loans, government subsidies/ budget …)
Organizational/ managerial	(OR1) Institutional capacity to manage and respond to disaster (examples: experience, know-how, resources, structure, leadership …)	(OR2) Parallel organizations to sustain operations during and after earthquake events (examples: governmental departments, NGOs …)	(OR3) Plans and resources to mitigate the negative consequences of a disaster (examples: finance, emergency plans, volunteer groups)
Cultural/ community competence	(CR1) Cultural features of communities that enhance collective actions and competences (examples: ethics, religious belief, values, ties, satisfaction, participation …)	(CR2) Alternative spontaneous actions driven by ethics and values in parallel with orderly organizational /institutional actions (examples: family ties, memberships …)	(CR3) Existence of cultural and community resources to enhance community's functions (examples: donations, volunteers …)

(*Continued*)

Table 2. (*Continued*).

Community Seismic Resilience Dimensions (Based on literature review)	Community Seismic Resilience Property (3Rs) (Adopted from Bruneau *et al*. 2003)		
	Robustness (Coping Capacity)	Redundancy (Adaptive Capacity)	Resourcefulness (Adaptive Capacity)
Physical/ Infrastructure	(PR1) Characteristics of built form and infrastructures to withstand seismic-induced damage and disruption (examples: retrofitted buildings/ infrastructures, density, …)	(PR2) Alternative physical assets to be employed if some elements loose function (examples: second homes, schools, hospitals …)	(PR3) Existence of financial, material, human, and technological resources and supplies to restore functionality of physical system
Environmental	(EvR1) The characteristics of an ecosystem that is either susceptible or resilient to external shocks (examples: climate, topography …)	(EvR2) Diversity of environmental assets allowing some components to compensate the loss or failure of other components (green infrastructures …)	(EvR3) Managing environmental resources in order to reduce harms and losses in future earthquake events (examples: environmental policies, plans and programs)

a given earthquake. We exclude the fourth resilience property, rapidity, from our framework because it is almost based on the sum of other three Rs. These three resilience properties (3Rs) are matched with six community seismic resilience dimensions (socio-demographic, economic, environmental, organizational/managerial, physical/ infrastructure, and cultural/community competence) in a matrix to better understand each dimension's role in enhancing the seismic resilience of a community (Table 2). For example, physical/infrastructure robustness can be measured by the characteristics of built form and infrastructure to withstand seismic-induced damage and disruption (examples: retrofitted buildings/infrastructures, density …). The matched codes also helped us to extract indicators that comprehensively address the resilience metrics at different phases of the disaster management cycle, especially pre-event and post-event phases.

5. Identifying and selecting indicators

The selection of major indicators that influence community resilience is a critical point for construction of Community Seismic Resilience Indices (CSRI). Since there is no guideline regarding the objective selection of data for the construction of indices, in this study the method of selecting primary indicators is based on three common subjective criteria (see also Nardo *et al*. 2008; Cutter, Burton, and Emrich 2010): (1) the justification of indicators by relevant literature; (2) selection of indicators that are conceptually congruent with our theoretical framework presented in Table 2; and (3) the availability and quality of data to measure indicators. In order to select the most appropriate indicators for measuring community seismic resilience, a total of 15 scholarly works proposing composite indices for measuring community resilience in general and community seismic resilience in particular, were selected. In the primary selection of scholarly works, attention has been focused on those works that have adopted a holistic approach to community resilience. Then, their proposed indices were fitted into our study framework. The indicators were subsequently filtered to remove those that were either unmeasurable in an urban context or unrelated to natural hazards. After the primary selection filter, a total of 89 indicators were extracted (Appendix A [see online supplementary material]). The indicators were later merged and revised based on the number of repetitions in different research, their relevance to seismic hazard, and their applicability to an urban context. In this stage the number of selected indicators was reduced from 89 to 48 (Appendix B [see online supplementary material]). Then, a group of five senior academics, familiar with the disaster management field, were consulted to revise the indicators, regroup and merge those indicators which seemed to represent overlapping qualities, and suggest new indicators which appear to be congruent with the context of our study. In this step, our index was reduced to 25 indicators. In the next step, the indicators were analyzed for significant high correlations (Pearson's $R > 0.60$) between individual indicators in each dimension and also between all indicators in our index. After removing highly correlated indicators, 23 indicators were employed in our final index. As presented in Table 3, each resilience dimension is divided into different categories and each category is defined by indicators. The description of each indicator and its impact on community seismic resilience (positive/negative) are also highlighted. The characteristics of each dimension are further illustrated.

5.1. Economic

The economic dimension refers to the community's livelihood stability and the municipality's financial capacity which attenuate community resilience in economic terms. The main resilience categories in this dimension are employment, housing capital, financial capital, and economic diversity (Cutter, Burton, and Emrich 2010; Renschler *et al*. 2010; Ainuddin and Routray 2012; Asadzadeh, Kotter, and Zebardast 2015; Khazai *et al*. 2015; Yoon, Kang, and Brody 2016; Kammouh *et al*. 2019). During the time of disruption, employed populations retain their monthly salary and are entitled to unemployment compensation which would render them more resilient. In Iran, land/home ownership is a source of economic prosperity for households and to some extent guarantees access to lending institutions. Landownership is also linked to people's livelihood stability and their attachment to place. The experience of Bam earthquake (2003) revealed that organized temporary camps was not a successful program since people preferred to stay in their own plots to resume farming and their livelihood (Khatam 2006).

Since the real estate market holds a high share of districts' revenues in Iranian cities, the number of construction licenses issued by each sub-city district is adopted in the financial category of economic resilience. The last indicator in this category is the economic diversity which is reflected in the ratio of large to small businesses. Previous research has indicated that businesses serving large markets recover from disaster much more rapidly in comparison to small businesses (Webb *et al.* 2000; Sauser *et al*. 2018).

5.2. Socio-demographic

The socio-demographic dimension of community seismic resilience is mostly related to the inherent characteristics of a community in terms of age, education, disability, and population exposure to hazard. It is expected that communities with more elderly/children, a lower level of education, and more people with disabilities will likely result in less resilience than communities that do not show these characteristics (Cutter, Burton, and Emrich 2010; Renschler *et al*. 2010; Ainuddin and Routray 2012; Asadzadeh, Kotter, and Zebardast 2015; Yoon, Kang, and Brody 2016). Furthermore, direct or indirect exposure to risks increases the risk of loss and disruption (Renschler *et al*. 2010; Verruci, Rossetto, and Twigg 2012; Asadzadeh, Kotter, and Zebardast 2015; Khazai *et al*. 2015). Therefore, in this category, we include district-level population density and the percentage of population living in high risk zones. The latter is calculated based on population living in the immediate area adjacent to the fault line, which is estimated at 300 meters in Mashhad. Other categories including race, ethnicity, and gender were eliminated from our index because of the population homogeneity we found in the districts of Mashhad.

5.3. Environmental

Environmental features, in terms of natural and geophysical factors, are also important in measuring community seismic resilience. Geophysical factors affect physical vulnerability of place and include land slope which increases the potential risk of landslide as a consequence of an earthquake (Renschler *et al*. 2010; Burton 2015; Yoon, Kang, and Brody 2016). Natural factors in our indices include green infrastructure in each sub-city district, which increases sheltering and emergency aid during and after an earthquake (Yoon, Kang, and Brody 2016).

5.4. Organizational/managerial

The organizational dimension of community seismic resilience is related to local government capacities to mitigate the hazard and to engage residents in hazard mitigation activities (Cutter, Burton, and Emrich 2010; Burton 2015). The main attributes of this dimension, according to Ostadtaghizadeh *et al*. (2016), are managerial process (legislations, plans, and policies), managerial resources (financial, technological, and human), and managerial qualifications (competences, knowledge, and skills). Indicators in this dimension include the financial resources for crisis management, the number of emergency management maneuvers, and the number of neighborhood emergency response volunteers in each district. Recently, the municipality of Mashhad has initiated a program for engaging citizens in a local disaster management scheme. The program, known as *davam-e-samen* (Neighborhood Emergency Response Volunteers), aims at training inhabitants of neighborhood to take responsibility in the event of a crisis in order to mitigate the impacts of hazards. Unfortunately, at the time of writing, we were unable to convince the Disaster Risk Engineering and Management department of the municipality of Mashhad to provide the necessary data for the organizational/

managerial dimension. However, for the convenience of future researchers we include organizational/managerial indicators in our indices' list but exclude them from the final calculations for community seismic resilience.

5.5. *Physical/infrastructure*

Resilience categories in the physical/infrastructure dimension include physical capital, infrastructure capital, and physical exposure to hazard. Deteriorated urban fabrics are often considered as one of the most important factors in urban vulnerability in Iran (see Asadzadeh, Kotter, and Zebardast 2015; Ostadtaghizadeh *et al*. 2016). According to the High Council of Architecture and Urban Development of Iran, deteriorated urban fabrics include three sub-criteria: 1) Fine-grained urban fabric (blocks with more than 50% of parcels less than 200 square meters), 2) Instability (blocks with more than 50% of parcels built with unstable materials and structural systems), and 3) Impermeability (blocks with more than 50% of passageways less than 6 meters wide). According to these criteria, in the administrative area of Mashhad's municipality about 2,303 hectares of deteriorated urban fabrics have been recognized. Indicators in the infrastructural capacity category are the number of healthcare centers and the number of emergency shelters, which are both important for disaster response and recovery. The last category in this dimension is the community's physical exposure to hazard, which is related to the location of the community's critical infrastructures (schools, hospitals, covered sport-fields, …) in the immediate area adjacent to fault line, which is estimated at 300 meters in Mashhad.

5.6. *Cultural/community competence*

Resilience categories in the cultural/community competence dimension are related to the community's social capital, cultural features and public satisfaction. A community's social capital is defined as "a set of adaptive capacities that can support the process of community resilience to maintain and sustain community health" (Burton 2015, 5). This article adopts inhabitants' perceptions of social trust and community participation as the main indicators of social capital. The former is extracted from the report of the research project on the Identification of Social Harms and Anomalies in Urban Neighborhoods of Mashhad (2015) and the latter is extracted from the number of citizens' phone calls to the Public Relations Center (137) in each municipal district. Recent studies have demonstrated that cultural aspects of communities could improve disaster resilience more effectively and rapidly (see Ostadtaghizadeh *et al*. 2016; Neher and Miola 2016). Furthermore, culture can systematically encourage a community to cooperate and overcome hardships through collective actions. Important proxies for the cultural dimension of resilience are spirituality, faith, and religiosity which contribute to the adaptive capacity of individuals and households by providing positive views, self-esteem, and social/psychological support (Alawiyah *et al*. 2011; Neher and Miola 2016). In Iranian cities, mosques and *Hussainiya*[3] have traditionally played an important role in social cohesion within neighborhoods. Beside their religious function, mosques are centers of cultural activities, education, neighborhood meetings, and faith-based charities. Therefore, the number of mosques and other faith-based centers in each sub-city district comprises the indicator for the cultural category of this dimension of resilience. Public

Table 3. Final community seismic resilience indicators.

Category	Indicators	Description	Impact
Economic resilience Occupation Housing capital Financial capital Economic Diversity	1. Percentage of employed population	Better access to credit, retirement and unemployment compensation	Positive
	2. Percentage of home ownership	Better maintenance and access to credit - Higher attachment to place	Positive
	3. Number of construction licenses issued by the district municipality in the last fiscal year	Higher incentives for investors, higher recovery priority by private sector, higher financial resources for recovery	Positive
	4. Ratio of large to small businesses	Businesses serving large markets recover rapidly in comparison to small businesses	positive
Socio-demographic Population exposure Education level Age Special needs	5. Number of population per 1,000 square meters	In the case of earthquake, larger number of people are prone to risk in densely developed areas	Negative
	6. Percentage of Population within high risk zones	Direct exposure to hazard increases the risk of loss and disruption	Negative
	7. Percentage of people with Higher Education level	Higher capacity to prepare for, and respond to, disasters	Positive
	8. Percentage of population aged between 6 to 65	Children aged under 6 and elderly aged above 65 are less mobile, more dependent, and rely on other's help during the earthquake and the post-earthquake recovery	Positive
	9. Percentage of people with physical/ mental disability	People in need of special care are more vulnerable due to their immobility and dependency on external helps	Negative
Environmental Exposure Vegetation	10. Percentage of the areas with a slope more than 4% in the neighborhood	Potential risk of landslide	Negative
	11. Natural/green areas per capita	Resilient areas suitable for sheltering	Positive
Organizational /Managerial Managerial resource	12. Municipal budget line of each district for crisis management and prevention	Financial resource for disaster risk prevention	Positive
	13. Number of emergency	Better knowledge and skills for safety	Positive

(*Continued*)

Table 3. (*Continued*).

Category	Indicators	Description	Impact
	management maneuvers	measures and rescue after the earthquake	
	14. Number of neighborhood emergency response volunteers per 1,000 people	Tendency to work together during crisis	Positive
Physical/ Infrastructure Physical capital Infrastructural capital Physical exposure to hazard	15. Percentage of deteriorated urban fabric	High vulnerability due to structural instability of buildings	Negative
	16. Number of healthcare centers per 1,000 residents	Capacity of health system to provide aid and medical cares for residents	Positive
	17. Number of emergency shelters per 1,000 people	Emergency shelters provide relief and recovery area for injured and dislocated people	Positive
	18. Percentage of critical infrastructures located inside high risk areas	Direct exposure to hazard increases the risk of loss and disruption	Negative
Cultural/ Community competence Social trust Religious ties Community participation Public satisfaction	19. Inhabitants' perception of social trust	Social trust results in better cooperation and faster recovery at the time of disaster	Positive
	20. Number of mosques and other religious-based per 1,000 residents	Faith-based organizations provide physical and social support beyond family and neighbors during times of crises	Positive
	21. Number of phone calls to Public Relation Center of each sub-city districts per 1,000 residents	Participation and involvement can increase social cohesion and contribute to higher adaptive capacity	positive
	22. Inhabitants' satisfaction toward life	Better cooperation with local government and faster recovery	Positive
	23. Percentage of Satisfaction from local councils	Better cooperation with local government and faster recovery	Positive

satisfaction is the last category in the cultural/community competence dimension of resilience, which promotes better cooperation with the local government and therefore, faster and more effective recovery.

6. Data normalization and aggregation of indicators

Once the indicators were selected, data for each sub-city district of Mashhad was extracted from official statistics (See Appendix C [online supplementary material]).

Since the range of values of different raw data was not identical, the variables were normalized using a min-max rescaling scheme to set all values into an identical range between zero and one (Equation 1).

$$x'_n = \frac{x_n - \min_{indic}}{\max_{indic} - \min_{indic}} \quad (1)$$

For indicators that have a negative impact on community seismic resilience, the rescaling process was done according to Equation (2).

$$x'' = 1 - \frac{x_n - \min_{indic}}{\max_{indic} - \min_{indic}} \quad (2)$$

After normalizing the indicators, the arithmetic mean of the scores in every single dimension was calculated for each sub-city district. The arithmetic mean helps to remove the influence of the different number of indicators in each dimension.

Once the indicators are normalized (See Appendix D [online supplementary material]), the next step is to assign weights to the indicators and dimensions. Because of the limited number of samples in the analysis (13 districts) we were unable to run Principal Component Analysis. Therefore, a group of ten multi-disciplinary local experts in disaster risk management were consulted to assign a priority to each indicator. However, results indicated the explicit bias experts clearly have for their own field of expertise. Moreover, based on previous similar studies, the authors did not find any objective weighing methods for aggregating composite indicators (For example in the analysis of 36 community disaster resilience frameworks by Sharifi (2016) 21 frameworks adopted equal weights to indicators). Therefore, in this study, we assign equal weights to all indices. The final resilience score for each district is presented in Table 4, which indicates the final scores for each district of Mashhad in different dimensions.

Table 4. Final resilience score for Mashhad's sub-city districts.

Rank	District	Final Resilience Score	Economic	Socio-Demographic	Environmental	Physical/ Infrastructure	Cultural/ Community competence
1	12	3.275	0.711	0.790	0.752	0.520	0.502
2	1	3.036	0.599	0.717	0.513	0.667	0.540
3	8	3.026	0.615	0.500	0.617	0.673	0.622
4	11	2.772	0.488	0.778	0.698	0.527	0.280
5	10	2.734	0.412	0.670	0.595	0.699	0.358
6	2	2.430	0.345	0.567	0.500	0.520	0.499
7	7	2.372	0.586	0.569	0.512	0.286	0.419
8	6	2.164	0.251	0.415	0.555	0.488	0.456
9	Samen	2.154	0.153	0.365	0.515	0.500	0.620
10	9	2.079	0.563	0.791	0.060	0.323	0.341
11	4	2.003	0.335	0.287	0.518	0.449	0.415
12	5	1.969	0.332	0.253	0.570	0.396	0.417
13	3	1.930	0.297	0.424	0.526	0.364	0.319

Table 5. Z-scores for Mashhad's sub-city districts.

Rank	District	Final resilience score	Economic	Socio-demographic	Environmental	Physical/ Infrastructure	Cultural/ Community competence
1	12	1.774	1.415	1.267	1.350	0.207	0.528
2	1	1.257	0.752	0.886	−0.122	1.328	0.876
3	8	1.235	0.844	−0.254	0.520	1.371	1.637
4	11	0.684	0.091	1.204	1.021	0.263	−1.526
5	10	0.602	−0.362	0.638	0.384	1.569	−0.801
6	2	−0.058	−0.760	0.098	−0.204	0.203	0.495
7	7	−0.184	0.670	0.112	−0.132	−1.577	−0.241
8	6	−0.635	−1.324	−0.696	0.133	−0.037	0.102
9	Samen	−0.657	−1.903	−0.959	−0.108	0.054	1.623
10	9	−0.819	0.538	1.274	−2.919	−1.296	−0.959
11	4	−0.985	−0.823	−1.366	−0.095	−0.339	−0.280
12	5	−1.060	−0.838	−1.546	0.227	−0.737	−0.257
13	3	−1.144	−1.050	−0.648	−0.044	−0.987	−1.162

7. Results of community resilience

After calculating each district's resilience scores in all dimensions and their final resilience score, results were processed through the z-scores method. The z-scores method is used to determine those districts that rank either higher or lower than the average resilience score and their spatial dispersion in the city. Positive scores indicate rankings above the mean and negative scores indicate rankings below the mean. Table 5 indicates the normalized resilience scores for each district.

8. Visualization of results

To discover whether there is any definite trend in the resilience of Mashhad's sub-city districts, the final scores were visualized into community resilience maps using Arc GIS software. Visualizing the results assists policy-makers and planners to compare different communities' capacities in times of hardship and to determine the logic behind the spatial dispersion of resiliency in the city.

There were 13 sub-city districts in our study. The average value of CSRI is 2.45 with a standard deviation of 0.46, a maximum value of 3.27 (most resilient), and a minimum value of 1.93 (least resilient). For visualizing the spatial pattern of community seismic resilience in Mashhad's sub-city districts, the scores were displayed as a five-category choropleth map using standard deviation:

- Low resilience (from −3 to −2 standard deviation)
- Relatively low resilience (−2 to −1 standard deviation)
- Moderate resilience (from −1 to 0 standard deviation)
- Relatively high resilience (from 0 to 1 standard deviation), and
- High resilience (from 1 to 2 standard deviation).

The dark brown color represents high resilient districts whereas low resilient districts are represented in light yellow color.

9. Findings

Figure 3 shows the spatial representation of community seismic resilience in sub-city districts of Mashhad, which includes five dimensions and twenty-three indicators. The final result illustrates that most districts are classified from moderate to highly resilient and only district 3 and district 4 are classified as relatively low resilient districts. In order to better understand the underlying factors for spatial distribution of community seismic resilience, the five dimensions of economic, socio-demographic, environmental, physical/infrastructure, and cultural/community competence are illustrated through choropleth maps (Figure 4). The result of mapping the economic resilience of Mashhad's sub-city districts indicates a considerable distinction between the northern and the southern districts of the city, where the southern districts are in a much better position (Figure 4A). On the other hand, northern districts are less resilient and struggle with economic challenges, including low income, unemployment and poverty. Moreover, there is a high concentration of squatter settlements in the northern periphery of Mashhad and many land areas of districts 2, 3, 4, 5, and 6 were once squatter settlements which have been annexed to the administrative area of Mashhad in the last two decades. The socio-demographic dimension of community seismic resilience indicates a gap between the eastern and the western districts of the city (Figure 4B). Districts 9, 11, and 12 are highly resilient in this dimension, whereas districts 4 and 5 are the least resilient districts in Mashhad due to considerable difference in education level, population density, and the number of inhabitants with a disability. The mapping of the environmental dimension of resilience shows that all sub-city districts of Mashhad, except district 9, are placed in the moderate to high resilient category

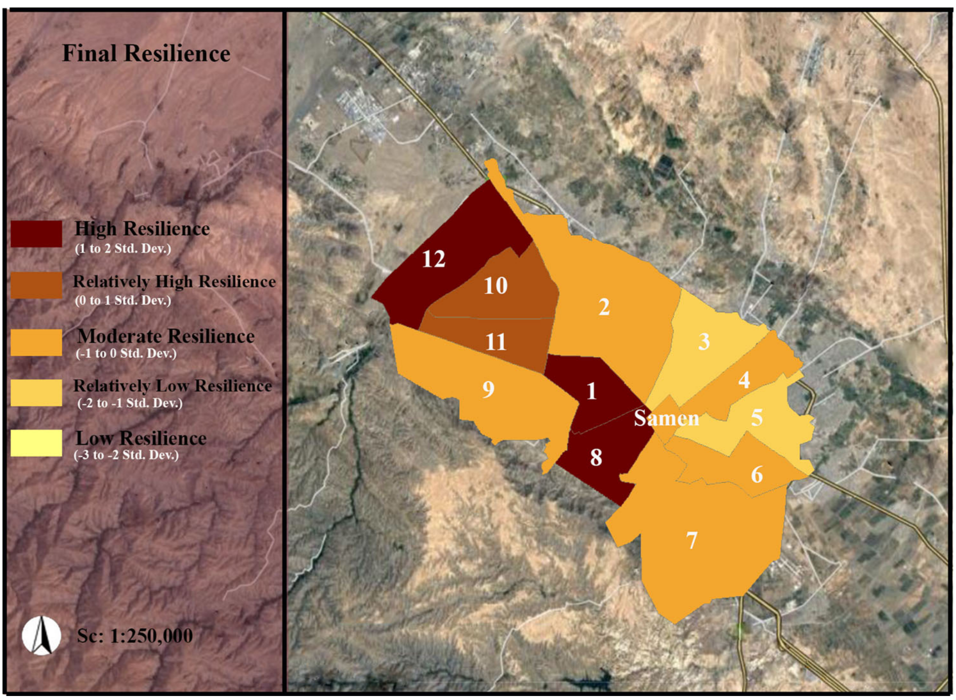

Figure 3. Spatial distribution of community seismic resilience in 13 sub-city districts of Mashhad.

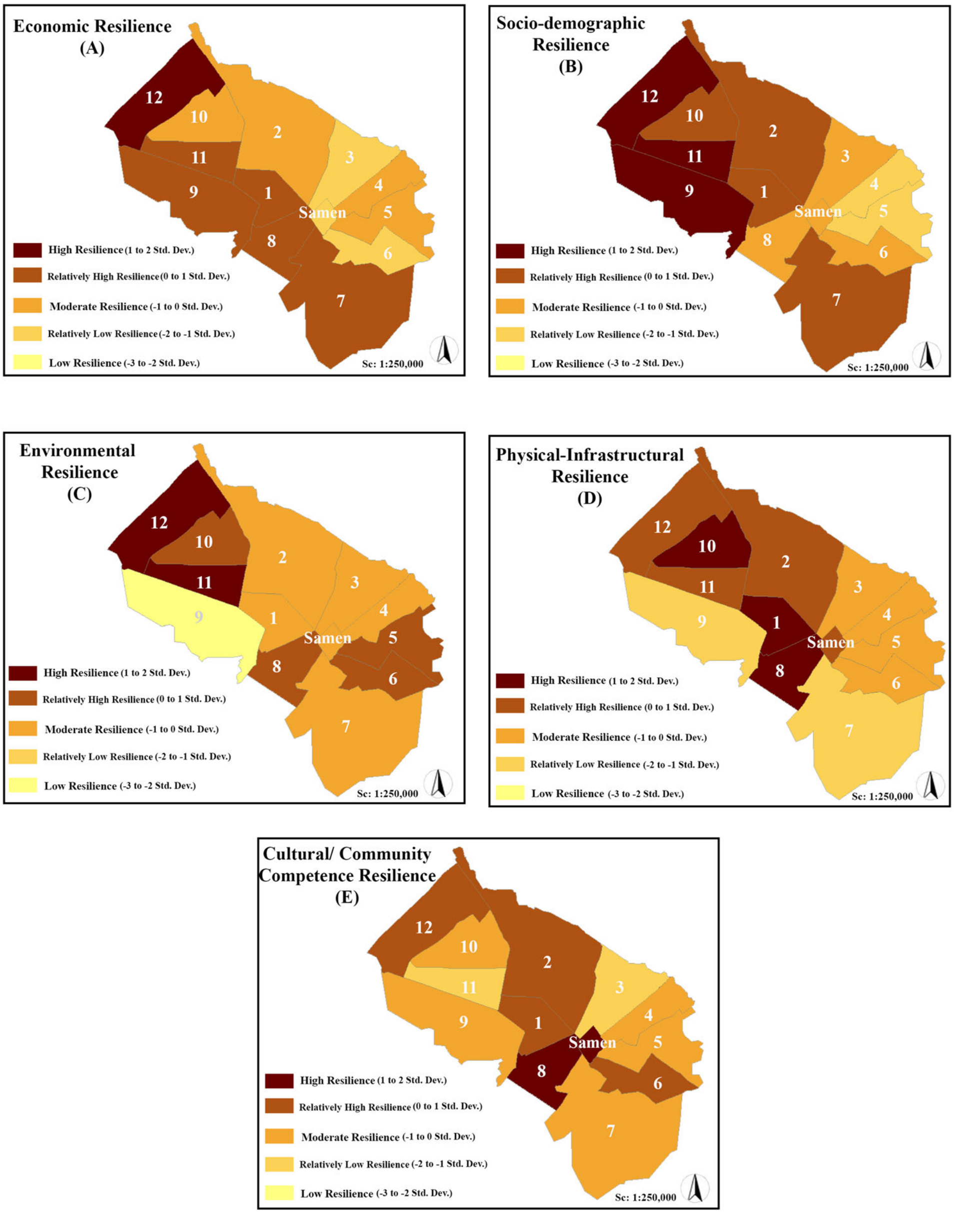

Figure 4. Spatial distribution of different dimensions of community seismic resilience in Mashhad.

(Figure 4C). District 9 has the lowest resilience in this dimension due to geophysical factors such as fault crossing and high land slope. The physical/infrastructure dimension of resilience displays a different distribution with higher scores in the western and the lowest scores in eastern districts Figure 4D). The cultural/community competence dimension of resilience displays a better condition for all districts where, except for districts 3 and 9, all districts are ranked from moderate to highly resilient (Figure 4E).

10. Discussion

CSRI provides a baseline to measure community seismic resilience in sub-city districts of Mashhad. The index also provides a reference point to monitor and compare districts in order to evaluate their performance over time. The CSRI can also help decision makers at local level to allocate resources and adopt initiatives and programs to enhance community resilience.

It is important to highlight that almost all indicators of community seismic resilience in this article could be addressed directly by policy for improvement. Indicators for social and economic inequality could be directly addressed by policies and plans to reduce gaps between districts. Exceptions are population age and people with disabilities that both require indirect programs that would not be reflected by the indicators in CSRI. Similarly, physical/infrastructure indicators could be directly targeted by plans and regulations to improve the robustness and redundancy of critical infrastructures in districts that have lower levels of resilience. Cultural/community competence indicators could be improved by adopting policies to enhance social capital and residents' participation in their district's affairs.

As for the geography of CSRI, our findings suggest that there is quite a clear east-west division in districts' resiliency in Mashhad, where districts that rank higher in total resilience scores (1, 8, 11, and 12) are located in the western part of the city and are linked together in a linear pattern that forms a backbone stretching from the central to the north-western area of the city. These districts have emerged in the past fifty years and are the main headquarters for key land uses/activities and the main service centers in the city of Mashhad. On the other side of the city, there is a cluster of districts ranking from moderate to low resilience scores forming a quasi-petal pattern around *Samen* district. These districts have gradually expanded over time and are mainly formed by the annexation of rural nuclei and peri-urban areas to the administrative boundary of Mashhad. In the following subsections the potential implications of the results of this study for planning, policy, and decision making are discussed.

10.1. Urban policies for enhancing the robustness of communities to seismic hazards

The socio-economic inequality in districts of Mashhad has established a pattern of spatially segregated resilience to seismic hazard. This gap could be directly addressed by policies, regulations, and plans to enhance the robustness of built form and infrastructure. It should be noted that deteriorated urban fabrics occupy significant areas of districts 3, 4, 5, and 6 which are characterized by structural instability of buildings, high population density, insufficient green/open space, and the inefficiency of urban infrastructures in these districts. At the same time, these districts are home to residents with lower educational levels and higher disability compared to other districts, which make them inherently vulnerable to seismic risks. In addition, the concentration of major transportation hubs in the eastern part of Mashhad (railway station, airport, bus terminal, and urban ring road) has resulted in fragmentation of urban fabric and spatial discontinuity which could diminish community cohesion and integrity (this hypothesis should be further analyzed in separate research). In order to enhance the robustness of urban systems to seismic hazard, urban policies could prepare disaster risk zonation plans, facilitate urban regeneration, envision new centralities, and reinforce emergency facilities (schools, hospitals, emergency shelters) in less resilient districts. There is also a need for cross-departmental cooperation to integrate aspects of disaster risk management in urban development plans. Currently, urban development plans (master plans and detailed plans) and crisis management activities are addressed through separate departments and follow different procedures from preparation to approval (Fekete *et al*. 2020). Therefore, it is suggested that aspects of resilience properties to be included in the terms of agreement for urban development plans and become a criterion for evaluating and approving land use plans, zoning regulations and community development schemes. Additional research could be conducted to measure the robustness of community lifelines (water pipes, gas pipes, urban roads, critical facilities) in sub-city districts of Mashhad to contribute to a more robust system.

10.2. Building redundancy into the crisis management system

Iran's crisis management system is very centralized and organized on two tiers: national and provincial. The approach of the disaster management structure is very multi-sectoral and there is no comprehensive, integrated and coordinated risk management among all involved sectors. In this structure, local governments have a weak role in disaster risk reduction policies and the main task of municipalities is only confined to monitoring the implementation of regulations, training managers/citizens, and upgrading safety equipment necessary at the time of hazard events (The municipality of Tehran is an exception) (Akbarpour *et al*. 2015).

Unlike Tehran, the city of Mashhad lacks a disaster risk management master plan and the municipality's intervention is accomplished through the department of Disaster Risk Engineering and Management (DREM). The activities of DREM include the design of passive defense schemes, establishing and coordinating district-based emergency response volunteer groups (*davam-e samen*), and locating multi-purpose emergency shelters for the city. The municipal government's action is directed more toward preparation and response to potential future risks than designing strategies for mitigation and enhancing communities' adaptive capacity. In fact, DREM's actions are concerned with outputs such as maps, reports, maneuvers, apps, etc. which highlight the "resistance" and "static" aspects of resilience rather than its dynamic and adaptive features. The *davam-e samen* volunteer structure is hierarchical and its main activity is focused on training staff for safety issues such as firefighting, rescue/relief, and the psychological care of disaster victims, which is not directly oriented toward community participation in disaster risk management. It is suggested that the department of Disaster Risk Engineering and Management in the municipality of Mashhad establishes horizontal links with universities, research institutes, NGOs, and community-based associations in order to exploit wide range of resources necessary for establishing a redundant managerial/organizational system.

11. Conclusion, recommendations, and limitations

This article provides a first attempt at developing a framework to measure community seismic resilience in sub-city districts of Mashhad, Iran. The theoretical framework and the selected indices are addressed specifically to seismic-related hazards and can be applied to other large cities in Iran for comparative purposes. CSRI will measure communities' performance over time and therefore it has policy and decision-making implications for enhancing the disaster-related capacity of a metropolis situated on fault lines. The results of this study indicate disparities in almost all dimensions of resilience between the eastern the western parts of Mashhad. Therefore, urban policies should pay attention to the least resilient districts through resource allocation and application of planning policies and regulations to enhance the robustness of the built form and to alleviate the socio-economic inequalities. The latter implies that local decision makers should take the existing issue of socio-economic inequality into account in their strategies for developing a resilient community at the city level. In addition, the local crisis management system needs to recognize and incorporate the value of diverse resources to establish a more redundant disaster management structure. Therefore, it is recommended that the planning department in the municipality of Mashhad establishes a bilateral collaboration with the DREM department, universities, and research centers to recognize the impact of policy choices and development proposals on the resilience of communities in Mashhad.

From a theoretical perspective, the contribution of this research is the melding of the engineering properties of resilience (3Rs) to a system's socio-cultural and economic capacities in order to build a composite index for measuring community seismic resilience. Unlike most community seismic resilience frameworks that adopt indicators relating to the coping capacity of a system (i.e. robustness), the CSRI also includes indicators relating to adaptive capacity in order to achieve an holistic assessment of seismic resilience.

There are also some limitations regarding this kind of index-based approach in assessing community seismic resilience. First, like several other frameworks, this study provides a top-down approach which does not take into account the perception and judgment of local residents in conceptualizing community seismic resilience. Second, the index is constructed on the availability of official data which is often out of date and sometimes inaccessible to the public. The latter is, unfortunately, the reason for excluding some important indicators (including institutional resilience indicators) from our index.

As community resilience is becoming a context-dependent phenomenon, the case of Mashhad constitutes a useful addition to the literature in this field. Indicators and policy-related discussions developed in this research provide a good insight for researchers, managers, and decision makers to understand place-specific, as well as hazard-specific, factors affecting the resilience of populations.

Notes

1. Given the availability of data, the unit of analysis can be extended to include wards (*Nahiyeh*) as the sub-category of districts.
2. Choosing secondary data is an accepted method in building composite indices. In a critical review of tools for assessing community resilience by Sharifi (2016), ten out of 36 selected tools mainly rely on secondary data only.
3. A *Hussainiya* is a congregation place for Shia Muslim mourning ceremonies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Supplemental data

Supplemental data for this article can be accessed online at https://doi.org/10.1080/09640568.2021.1902790.

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