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A Brief Review of Vulnerability, Preparedness and Resilience Measures of Anticipated Istanbul Earthquake

Beklenen İstanbul Depreminin Hasar Görebilirlik, Hazırlıklılık ve Afet Direnci Açısından Öz Bir Derlemesi

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Öne Çıkanlar / Highlights

Öne Çıkanlar	Highlights
▪ İstanbul beklenen depreme yönelik yüksek risk ve hasar görebilirlikle karşı karşıyadır.	▪ Istanbul possesses vulnerability and high risk in terms of the anticipated earthquake.
▪ Risk azaltma çalışmaları yenilikçi teknolojileri multisektörel yaklaşımla entegre etmeli ve şehrin direncini arttırmada toplum bilinci ve katılımını arttırmalıdır.	▪ Mitigation efforts emphasize the necessity of integrated, multisectoral approaches and the incorporation of innovative technologies including community awareness and engagement.

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Keywords

Istanbul, Earthquake, Preparedness, Risk Mitigation, Urban Resilience, Disaster Management, Community Engagement, Vulnerability, Emergency Response.

Özet

Bu çalışma, Asya ve Avrupa kıtalarının kesiştiği noktada yer alan ve Kuzey Anadolu Fayı (KAF) nedeniyle önemli deprem riskleriyle karşı karşıya bulunan İstanbul'un sismik kırılganlığını incelemektedir. Tarihsel sismik olaylar, kentsel gelişim modelleri ve mevcut bina ile altyapı direncine ilişkin verilerin sentezlendiği bu derleme, yoğun nüfuslu ve hızlı büyüyen bir metropolde afet yönetiminin karmaşıklıklarını ortaya koymaktadır. Yasal çerçeveler, kentsel planlama politikaları ve topluluk bazlı direnç girişimleri dahil olmak üzere, mevcut hazırlık ve zarar azaltma stratejilerinin etkinliği kritik bir şekilde değerlendirilmektedir. Bu inceleme, deprem riskini azaltma konusundaki mevcutyaklaşımlardaki eksiklikleri belirlemekte ve şehrin gelecekteki sismik etkinliklere karşı dayanıklılığını ve toparlanma kapasitesini artırmak için entegre, çok sektörlü bir yaklaşımın gerekliliğini vurgulayarak iyileştirme önerileri sunmaktadır. Bulgular, İstanbul'u dirençli hale getirmede proaktif planlamanın ve yenilikçi teknolojilerin benimsenmesinin önemini vurgulamaktadır.

Abstract

This review examines the seismic vulnerability of Istanbul, a city uniquely positioned at the crossroads of Asia and Europe and exposed to significant earthquake risks due to the North Anatolian Fault (NAF). By synthesizing data on historical seismic events, urban development patterns, and current building and infrastructure resilience, the paper highlights the complexities of disaster management in a densely populated and rapidly growing metropolis. It critically evaluates the effectiveness of existing preparedness and mitigation strategies, including legislative frameworks, urban planning policies, and community-based resilience efforts. The review also identifies gaps in the current approach to earthquake risk reduction and suggests areas for improvement, emphasizing the need for an integrated, multi-sectoral approach to enhance the city's capacity to withstand and recover from future seismic events. The findings underscore the importance of proactive planning and the adoption of innovative technologies in building a resilient Istanbul.

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1.INTRODUCTION

The devastating consequences of the February 2023 earthquakes in southeastern Türkiye, which claimed nearly 50,000 lives and caused extensive injuries and financial losses, have underscored the urgent need to reevaluate earthquake preparedness and response strategies in Istanbul, a city marked by its significant demographic and structural vulnerabilities.(Hussain et al., 2023)

Istanbul, bridging Asia and Europe, is not only Türkiye's most populous city but also a significant cultural and economic hub. The city's unique geographic location on the Marmara Sea, adjacent to the Bosphorus strait, has historically made it a strategic epicenter for commerce and culture. With a population exceeding 16 million, Istanbul's demographic diversity and urban density add layers of complexity to disaster management and resilience planning (Eri et al., 2023).

Istanbul, spanning a surface area of 5,712 km² and encompassing 39 districts, is home to about one-fifth of Türkiye's population. Recognized as the 34th most crucial city in the global economy, Istanbul's strategic geopolitical location and its role as a major commercial and industrial hub have made it a magnet for immigration (AFAD, 2020). Annually, the city attracts an estimated 15-20 million international tourists (Eurocities, n.d.). Additionally, it is believed that Istanbul hosts approximately 2.5 to 3 million foreigners and refugees, figures that are not accounted for in the official population statistics (TUIK, n.d.).

The devastating impact of the two major earthquakes in 1999 in Türkiye led to a widespread consensus among government bodies, non-governmental organizations, and academic institutions on the urgent need for comprehensive response planning. This planning is based on in-depth risk assessments of potential seismic hazards in Istanbul (Erenoglu & Erenoglu, 2015).

Over recent years, rapid and unchecked urban growth, flawed urban planning and construction practices, inadequate infrastructure and services, and environmental degradation have all contributed to escalating earthquake disaster risks in Istanbul (Ay & Demires Ozkul, 2021). Another significant factor heightening this risk is the markedly increased likelihood of a major earthquake, currently estimated at about 65% in the next 30 years (Parsons, 2004). The high probability of such a seismic event occurring in Istanbul underscores the critical need for well-designed preparedness and emergency response strategies to be in place both before and in the aftermath of an earthquake. A thorough understanding and quantification of an earthquake's impact on both the physical infrastructure and the social fabric of Istanbul are essential for accurately depicting the seismic risk.

2. HAZARD ASSESMENT

2.1. LIKELIHOOD AND SEVERITY OF A POTENTIAL EARTHQUAKE IN ISTANBUL

The Marmara Region, particularly Istanbul, is located near the North Anatolian Fault (NAF) shown on figure one, one of the world's most active and well-studied strike-slip fault systems. The NAF extends across northern Türkiye, marking a tectonic boundary between the Anatolian and Eurasian plates. This proximity to a major fault line predisposes the region to significant seismic hazards (Kozacl & Altunel, 2022). Historical records reveal that the region has experienced numerous earthquakes including the one on 1999 in İzmit with devastating consequences claiming 16 thousand lives (Kayaalp & Arslan, 2022).

The likelihood and the severity of a potential earthquake in NAF has been studied thoroughly in the literature. Seismic hazard assessments have been conducted with a focus on a potential future catastrophic earthquake (magnitude greater than 7) along the primary deformation zone, the North Anatolian Fault (NAF) as shown in figure one, within the broader North Anatolian Shear Zone. Despite the relatively low frequency of seismic events in Istanbul and the challenge of distinguishing seismic activity from other ground disturbances like blasts, there have been noticeable events (with magnitudes ranging from 3.0 to 4.5) on both sides of the city (Lange et al., 2019). These occurrences, along with their focal areas, are considered potential sources for a future significant earthquake (Tan et al., 2022).

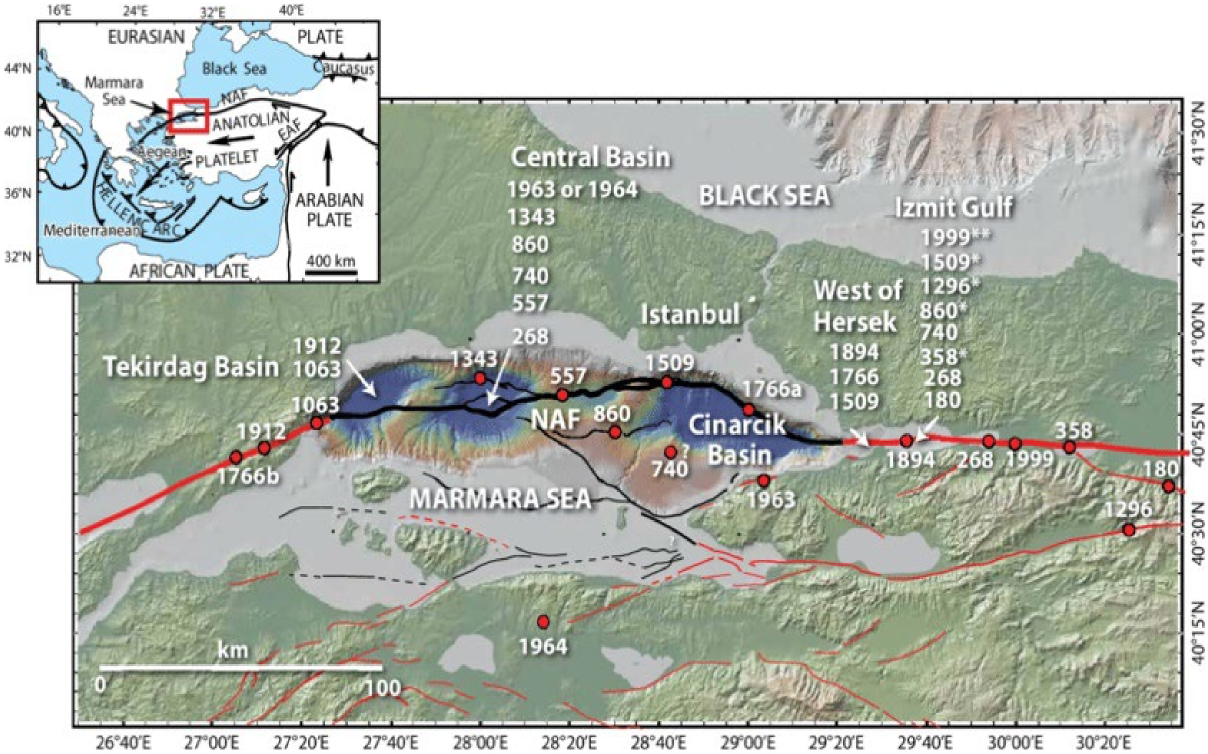

Figure 1. *Tectonic setting for the North Anatolian fault (NAF) (McHugh et al., 2014)*

More concisely, Research by Parsons in 2004 has indicated that using a time-dependent model, which incorporates both co-seismic and post-seismic effects of the 1999 M=7.4 Izmit earthquake, there is a 35-70% chance of an earthquake of magnitude 7 or higher occurring beneath the Sea of Marmara in the next 30 years (Parsons, 2004).

2.2. THREATS AND VULNERABILITY

Though various factors such as geological, sociological, and economic conditions influence earthquake vulnerability, three main factors are discussed here in evaluating earthquake vulnerability of Istanbul: (i) local soil conditions, (ii) building inventory and stock, and (iii) proximity to active faults.

Local soil conditions: The characteristics of local soil play a crucial role in defining an earthquake's impact. Soil properties significantly influence geotechnical behavior, affecting factors like ground amplification, liquefaction, landslide risks, and bearing capacity loss. The interaction between local soil properties and earthquake motions is critical in determining the structural load during an earthquake (Trovato et al., 2022). Figure 2's Ground Structure Suitability Map for Istanbul highlights the southern areas near the Sea of Marmara as high-risk due to potential liquefaction and flooding from earthquakes. These regions, shown in dark red, are densely populated and contain the greatest number of vulnerable buildings.

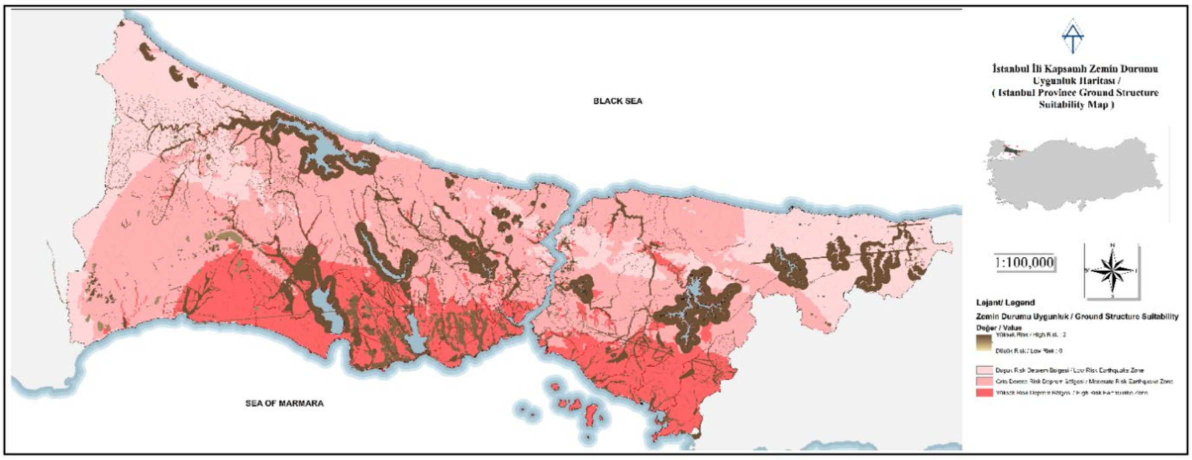

Figure 2. *İstanbul Province Ground Structure Suitability Map (BOUN, 2003)*

Building inventory and stock: The city's building stock totals 1,165,526 structures, reflecting varied architectural eras and styles. About 23% of these buildings predate 1980, 47% were constructed between 1980 and 2000, and 30% post-date the year 2000. In terms of height, 65% of the buildings range from 1 to 4 storeys, 32% are between 5 and 8 storeys, and a smaller proportion, about 3%, ranges from 9 to 19 storeys (AFAD, 2020).

In 1999, 2007 and 2018, the Turkish government introduced legal regulations to enhance the resilience of structures against disasters. However, a significant challenge for Istanbul's disaster resilience lies in the fact that nearly %70 of its buildings was constructed prior to the implementation of these regulations. This situation represents a critical vulnerability in the city's capacity to withstand earthquakes (Erdikt et al., 2003).

Proximity to active faults: The destructive potential of an earthquake in Istanbul is amplified by the NAF beneath the Marmara Sea, which threatens the city's most densely populated coastal districts. While all of Istanbul's districts are at risk, areas such as Adalar, Avcılar, Bahçelievler, Bakırköy, Beylikdüzü, Büyükçekmece, Küçükçekmece, Maltepe, Tuzla, Üsküdar, Zeytinburnu, and Sultanbeyli, along with their adjacent neighborhoods, are particularly vulnerable due to their closeness to the fault line. The majority of the pre 2000 built buildings are located in these districts which have been also classified as high risk in the Figure 2 (AFAD, 2020; BOUN, 2020; JICA & IMM, 2002).

2.3. ANTICIPATED IMPACTS

In 2002, the "Disaster Prevention and Mitigation Basic Plan" was published through a collaboration between the Istanbul Municipality and the Japan International Cooperation Agency (JICA)(JICA & IMM, 2002). This initiative was reassessed in 2020 by Boğaziçi University with the objective of updating Istanbul's potential earthquake loss estimates (BOUN, 2020).

The JICA study proposed two scenarios for an earthquake of either 7.5 or 7.7 magnitude in Istanbul. Below, Table 1 compiles findings from the report, drawing upon loss and damage estimates tied to a dataset from 2002 that includes roughly 750,000 buildings, 3,040,000 households, and a total population of 9,000,000.

Table 1 *Estimated Loss and damage summary (JICA & IMM, 2002)*

Category	*Estimated (according to JICA report)*
Building damage	50,000 to 60,000 buildings sustaining heavy damage,
Household loss	500,000 to 600,000 families becoming homeless,
Human loss	A death toll of 70,000 to 90,000 individuals,
Injuries	120,000 to 130,000 people suffering serious injuries with an additional 400,000 experiencing minor injuries,

Water infrastructure	1,000 to 2,000 instances of water leakage,
Gas Network	30,000 disruptions in natural gas flow,
Electric lines	A 3% failure rate in electrical cables,
Debris	The generation of 50 million tonnes of rubble,
Total financial loss	Material losses estimated at approximately USD 40 billion,
Humanitarian Efforts	The need for rescue operations for 1,000,000 individuals,
Sheltering	And the requirement of 330,000 tents for emergency shelter.

In the "Istanbul Metropolitan Municipality, Istanbul Province Possible Earthquake Loss Estimates Update" report by Boğaziçi University, while similar numerical estimates are presented as JICA report, a distinct estimation model is utilized. This model forecasts that around 640,000 households in Istanbul might require emergency shelter after an earthquake, potentially impacting about 2 million people (BOUN, 2020).

Damaged infrastructure: The natural gas, water, and electricity networks are anticipated to be damaged. The Boğaziçi model illustrates that, there would be 355 instances of natural gas leaks and 463 separate points of water pipe damage. Additionally, it is predicted that power and telecommunication lines would have 5% moderate damage and 19% light damage (BOUN, 2020; Gul et al., 2020).

Debris: A crucial concern is the management of post-earthquake debris. There are not adequate dumping sites for the tonnes of debris, and its removal could take years, posing a significant challenge in the aftermath of the earthquake (IMM, 2021).

Operational challenges in find and rescue efforts: The collapse or severe damage of buildings, especially along the single and dual carriageway roads will lead to the closures that could significantly hinder find and rescue efforts, making some operations difficult or even impossible(IMM, 2009). The map illustrates predicted road blockages in Istanbul post-earthquake, highlighting the potential for significant disruption to rescue operations, particularly in districts like Beyoğlu, Şişli, and Alieyköy. Areas in red are at high risk for isolation (BOUN, 2003; JICA & IMM, 2002).

3. MITIGATION MEASURES

Evidence indicates a substantial likelihood of a severe humanitarian crisis in the event of this anticipated earthquake in Istanbul. The potential for extensive building damage, significant road blockages, and consequent disruptions to critical infrastructure suggests that Türkiye could face considerable challenges in emergency response and recovery efforts (Adıkutlu, 2019). It is essential for disaster preparedness plans to address these risks proactively to mitigate the impact.

Mitigation efforts necessitate intricate and comprehensive collaboration across multiple sectors. The aftermath of an earthquake disaster can have enduring great social, political economic, and health impacts (Ay & Demires Ozkul, 2021). Therefore, addressing the potential consequences of such a disaster begins at the grassroots level, involving diverse sectors in a collaborative approach. The mitigation strategies presented here are categorized into two types: emergency response and mitigation measures.

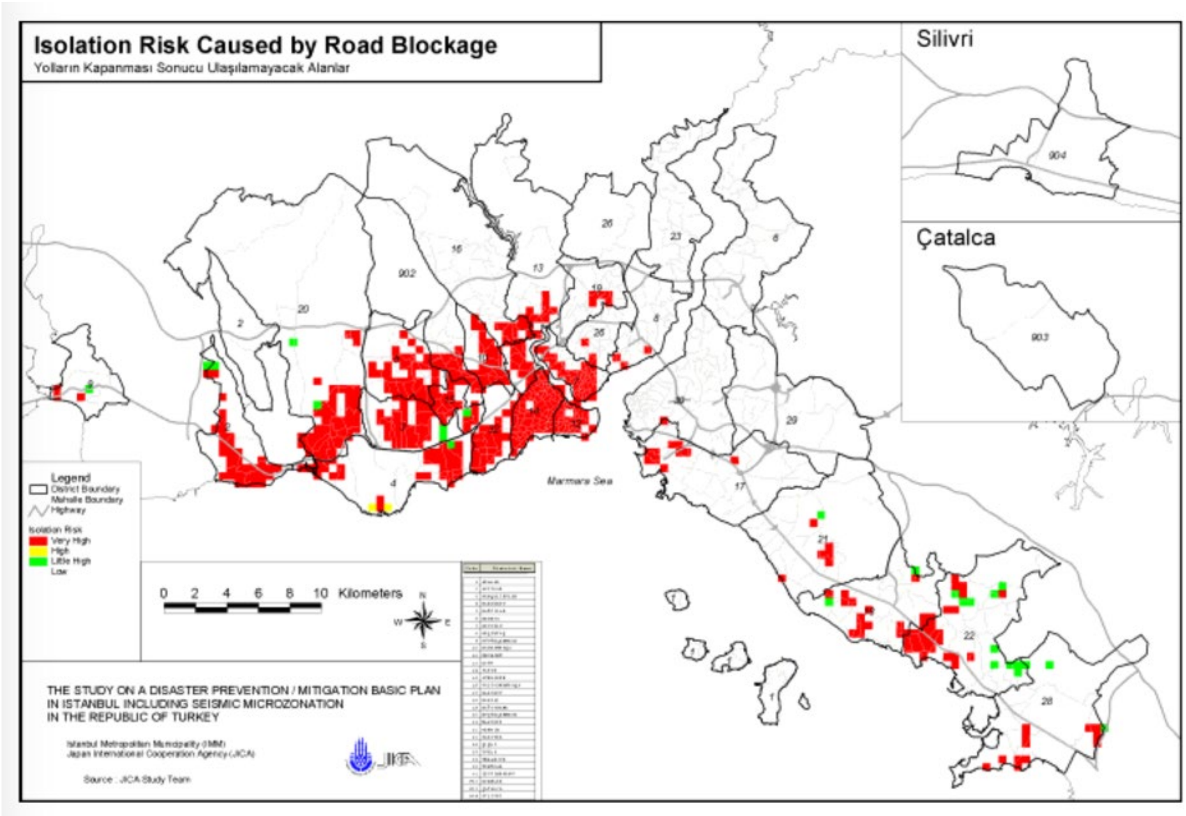

Figure 3. *Isolation Risk Caused by Road Blockage in Istanbul earthquake (JICA & IMM, 2002)*

3.1. Emergency Response

While emergency response measures are essential, they are inherently reactive and focus on immediate effects rather than long-term recovery or prevention (UNDRR, 2023). While they are generally feasible and affordable, their success is limited to the short-term management of a disaster. Furthermore, these measures do not address the underlying risk factors that contribute to the severity of a disaster's impact. To improve, there should be an integration of these measures with long-term resilience-building strategies, such as infrastructure improvements and community education programs, to create a more holistic approach to disaster mitigation. Some mitigation measures recommended for Istanbul are:

Local Evacuation Areas: Designate and prepare open spaces such as parks, schoolyards, and sports fields in every neighborhood as evacuation zones. Ensure these areas are equipped with emergency supplies and clear signage for easy identification by residents (Kako et al., 2017).

Debris Removal for Emergency Access: Deploy predetermined teams with heavy machinery immediately post-disaster to clear key transportation routes of debris. This will facilitate the movement of rescue and medical teams as well as the transportation of the injured to medical facilities (IMM, 2021; JICA & IMM, 2002).

Emergency Rescue Operations: Establish a system of rapid assessment teams to identify the most critically damaged buildings and prioritize rescue efforts. Train local volunteers to assist professional teams in extracting individuals trapped in partially collapsed structures (GDPC, 2023).

Emergency First Aid and Medical Care: Set up mobile first aid stations with trained personnel and necessary supplies in close proximity to identified evacuation areas. These stations should be capable of moving with the shifting needs of the affected population (de Oliveira et al., 2019).

Firefighting Operations: Pre-allocate firefighting resources to areas with a high concentration of hazardous materials and establish a protocol for the rapid deployment of these resources in the event of fires.

Provision of Portable Water and Food: Stockpile essential non-perishable food items and bottled water in secure yet accessible locations across the city. Create a distribution plan that can be activated immediately following the earthquake to provide supplies to displaced individuals.

Tent Cities and Temporary Housing: Pre-designate areas that can be quickly converted into tent cities. Secure a stock of tents, bedding, and basic living supplies that can be distributed rapidly. Formulate a registration process for displaced individuals to efficiently allocate temporary housing (Zhang et al., 2012).

Cemetery and Burial Services: Identify and prepare additional burial sites to accommodate an increase in fatalities. Ensure that processes and resources for dignified burials are in place, including the acquisition of necessary materials and personnel.

Infrastructure Strengthening: Enhance critical structures like ports, roads, bridges, hospitals, schools, and utilities (water, gas, electricity). This fortification ensures these vital systems remain functional during earthquakes, facilitating effective response and recovery (IMM, 2018).

Rubble Removal: Contract with construction and demolition companies in advance for the removal of debris, and earmark areas for the safe disposal of rubble. Establish a clear chain of command to coordinate these efforts without interfering with rescue operations (IMM, 2021).

Emergency Transportation Network: One of the biggest challenges in potential Istanbul Earthquake is the road closures expected due to the rubbles of buildings. Develop a structured emergency transportation network with primary, secondary, and tertiary routes connecting critical locations like disaster management centers, airports, and ports. This network should facilitate rapid disaster response and efficient movement of emergency services. Regular updates and clear traffic regulations are vital to keep these routes functional during an emergency (BOUN, 2003; JICA & IMM, 2002).

Strengthening Disaster Management Centers: Enhance the capabilities of disaster management centers at various levels to ensure quick and effective response. These centers should be equipped with necessary communication systems, emergency supplies, and trained personnel. Coordination between central and local governments is crucial for the operational effectiveness of these centers (JICA & IMM, 2002; UNDRR, n.d.).

Enhanced Monitoring and Early Warning Systems: Invest in advanced seismic monitoring and early warning systems. This technology can provide critical information for timely evacuations and immediate response actions (IMM & BOUN, 2021).

3.2. RISK REDUCTION

Resilience measures are more long-term goals requiring multi sectoral involvement and community engagement. These measures are easier to achieve by and with public awareness and contribution. Since it requires significant number of financial allocations and the result of these efforts are not always rapidly observed, public involvement is very important to keep these efforts in the agenda (UNDRR, n.d.). Also, for Istanbul case, some measures mentioned here might come with a material loss or extra expenses for vulnerable property owners therefore a lot of people do not agree their properties to be rebuilt (GAO, 1993). Despite the financial challenges, these measures are very sustainable and long-term effective. Key resilience measure identified are:

Strengthening Vulnerable Urban Structures: Prioritize retrofitting and reinforcing buildings identified as vulnerable in the earthquake risk analysis. This involves upgrading construction standards, especially in densely populated areas and those with historical significance (Varum, 2003). This measure is the most important yet the most difficult to achieve since %70 of the buildings in Istanbul might be vulnerable. Challenges start even in the phase of identification of such buildings since the property owners refrain from the financial losses.

Guidelines for Land Use and Legislation: Implement strict building codes and land-use policies that mandate earthquake-resistant construction. This includes revising zoning laws to limit construction in high-risk areas and enforcing building regulations more rigorously (Garrido & Saunders, 2019).

Developing the Institutional System for Disaster Management: Establish a robust institutional framework at the national, regional, and local levels. This framework should facilitate coordination among various stakeholders, including government agencies, NGOs, and community groups, for effective disaster response and mitigation (Jillson et al., 2019).

Establishment of a Credit System for Earthquake Resistant Housing: Create financial incentives and support mechanisms, such as low-interest loans or subsidies, for homeowners and developers to build or retrofit properties to be earthquake-resistant(Anbarci et al., 2005).

Encouraging Research on Earthquake Resistant Buildings: Foster partnerships between government bodies, academic institutions, and the private sector to research and develop new earthquake-resistant building materials and technologies. Promote innovation in construction techniques that are both cost-effective and culturally appropriate.

Urban Redevelopment Planning: Develop comprehensive urban redevelopment plans focusing on areas with high damage risk. These plans should involve community participation and aim to improve current urban structures while preparing them against future earthquakes (Waite, 2016).

Environmental and Cultural Site Protections: Safeguard historical and cultural sites by integrating conservation and earthquake resilience in their management. This includes structural assessments and reinforcements of historical buildings and sites (BOUN, 2003).

Community engagement and awareness campaigns: Focus on continuous public campaigns educating residents about earthquake safety. Carry out community-based information sharing, conduct rescue drills, and collaborate with NGOs, municipal bodies, and academics to ensure effective disaster preparedness(CDC, 2019). Engage local communities in the planning and implementation of resilience measures. Encourage local initiatives and programs that promote resilience and preparedness at the neighborhood level (Westen et al., 2023).

4. CONCLUSION

Istanbul is densely populated and still attracts migration. The population reduction is a key component in the urbanization and land use strategies. It is not articulated in this article as it is seen out of the mitigation concept and is a different comprehensive topic for discussion. However, the measures mentioned here should be analyzed before implementation in terms of their contribution to population reduction in Istanbul.

Resilience measures in Istanbul, aimed at long-term earthquake preparedness, involve challenges and strengths. Their proactive approach targets root causes of vulnerability, making them crucial for sustainable disaster mitigation. However, implementing these measures requires significant financial investment and community engagement, which can be challenging given their long-term nature and less immediate visibility of benefits. Key strategies include reinforcing buildings, updating zoning laws for earthquake resistance, improving disaster management systems, financial support for safer housing, and advancing relevant research. Balancing these with immediate emergency response needs is essential for a comprehensive approach to disaster preparedness in Istanbul.

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