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The Assessment of Road Network Vulnerability in Formal and Informal (slum) Urban Tissues to Earthquake Hazards With Crisis Management Approach (Case study: Zone 1 Tabriz)

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ABSTRACT: The urban road network is one of the main components of the city's lifelines that especially after crisis play significant role including the rescue operation, evacuation of the wounded and ... So the analysing of the urban road network besides planning for reducing these harms, are inevitable. In this paper, to evaluate urban road networks vulnerability of Zone 1 of Tabriz, 3 main criteria of density, level of inclusion and building features were employed which each of these criteria are divided into some sub-criteria that these sub-criteria were weighted using Delphi method. Ultimately, after evaluation of roads vulnerability in terms of each criterion, the layers were overlaid using multi criteria evaluation. The obtained results show that, the roads network vulnerability in region 1(planned tissues) is lower than middle and about 61 percent vulnerability of them is very low. The very high vulnerability is observed mostly in informal settlements area that it is about 96 percent.

Keywords: Crisis management -Vulnerability-Urban road network.

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INTRODUCTION

Researchers draw attention to the increasing complexity of the cities (Barbat et al., 2006), ever increasing dependency of the urban areas to major public utility systems (Barbat et al., 2006). In this regard lifelines are those systems that are vital for the continued operating of communities in an industrialized society. Even without an earthquake, the disruption of any one of lifelines, even for a day, would constitute a major disaster. In the aftermath of a damaging earthquake, many of these systems play a critical role for the emergency response community and the community in general to save lives and prevent additional damage to property (Schiffand Buckle, 1995).

Transportation infrastructures are considered by some authors as the most important lifeline system, largely because damage to it inhibits interventions on housing and other lifeline systems (Caiado et al., 2012). Transportation networks are an indispensable component of everyday life in the modern society (Chen et al., 2007). It is an accepted fact that, of all the modes of transport, road transport is the major means of transport to the people (Anbazhagan et al., 2012). The road transport system has to fulfil a number of different purposes, one of the most important being to allow people to commute efficiently and reliably. The road network may be able to meet this demand under ideal conditions, i.e. when all road links are operating at their full capacities (Jenelius, 2010). Road networks ability to connect spatially separated locations is vital for the accessibility and welfare of people and the economic efficiency of businesses. As a result, unplanned degradations in the system, when they occur, often have severe consequences (e.g., Wesemann et al., 1996; Zhu et al., 2010). In the case of damage produced by seismic events, the effects of an interruption to the road network and the consequent reduction of what remains available profoundly affect the overall performance of the system (increasing travelling time, distance and costs) (Salvatore, 2010). In the worst cases, such disruptions can threaten the possibility for some people to receive medical care and other critical services (Jenelius and Mattsson, 2012).

Analysis of road network vulnerability is very important in road network planning, construction and management. Nowadays, the concept of road network vulnerability is not uniform. It was Berdica who first proposed the concept. According to him, road network vulnerability is a sensitivity coefficient that is easily affected by accidents and finally makes the service level decline sharply (Luping and Dalin, 2012).

In terms of civil engineering and urban planning, injuries and the resulting fatalities associated with earthquakes vary tremendously from one event to the next. Both the number and severity of injuries are related to a number of factors including the magnitude of the earthquake, its proximity to a populated area, the soil type, building construction, time of day and population characteristics and behaviours (Bourque et al., 1997). By combining the principles of civil engineering and urban planning regarding natural hazards, human safety may improve.

This paper is concentrated on the comparison of road network vulnerability in two sites of the Tabriz city zone 1 which are known as official and non-official (slum) districts. The findings of this article will identify the high risky roads.

Literature Review:

A variety of approaches have been developed to assess network vulnerabilities. For example: To determine the weaknesses in the network, D'Este and Taylor (2001, 2003) used link choice probabilities, which can be calculated in a stochastic traffic assignment model using Bell's method (Bell, 1995). Jenelius et al. (2006) introduced the concepts of link importance and site exposure. Based on the increase in generalized travel costs when links are closed, they derived several link importance indices and site exposure indices. The measures were calculated for the road network of northern Sweden with 4470 nodes and 6362 links. However, they assumed inelastic travel demands for computational reasons. Asakura (2007) discussed the requirements of network flow models that were used for transport network reliability analysis. He suggested that the flow models developed for an ordinary network state would be modified and applied to the recovery state of a network. The network flow model should have the characteristics of explicit link capacity constraints, decreasing demand due to traffic congestion and the uncertainty of a traveller's choice behaviour.

Bono and Gutiérrez (2011) by employing simple combination of graph theory concept and spatial analyses using GIS, assess the isolation of urban blocks as a major conclusion of roads degradation.

In the majority of the previous studies after determining the average weights of criteria and sub-criteria, all parts of road networks were weighted equally without considering the flexibility of the different parts of the road while different parts of a road, according to the particular condition of roads, in one hand and considering it's surrender (e.g. adjacent buildings, density and…) on the other hand, needs it's specific weights. So in this study we try to assess the road networks vulnerability, by transferring attributes of each parcel to it's adjacent road, according to kernel's characteristic and don't use the equal weights for all part of roads.

Study Area

City of Tabriz as one of the major cities of Iran, located in active seismic areas is an earthquake prone region based on the historical records available. Tabriz north fault is known as one of the hazardous faults of the Iran country. This fault makes this city and especially zone 1, the most dangerous region in comparison to the other zones and cities. Additionally, this fault is enumerated as one of the rudimentary tectonic structures in the north-east side of the Urmia Lake (Ahmadi, 2011). The following major earthquakes have occurred in connection with the Tabriz North Fault:

Tabriz zone 1 with 211340 occupants is in the range of the most populous zones of Tabriz which is located in north side of the city. By considering fault maps of the city, it can be understood that this zone has been placed in the nearest district to Tabriz north fault [Ibid]. Tabriz zone 1 is divided into 5 regions which is shown in Figure 1. Region 1 is considered as planned district, while region 5 is recognized as informal residential area[1]. Physical characteristics of slums not only do the consequences magnify the natural or man-made disasters, but also hinder rescue efforts (Sapir and Lechat, 1986).

Table 1. Major occurred Earthquakes related to North fault of Tabriz

Date	Magnitude	Intensity
858. AD	6	VII
1042. AD	7.6	X
1721. AD	7.7	X
1780. AD	7.7	X
1960. AD	5.1	VI, VII

(Source: Firuzi, 2009)

This paper examines the road network vulnerability of both formal and informal residential areas (regions 1 and 5) against earthquakes.

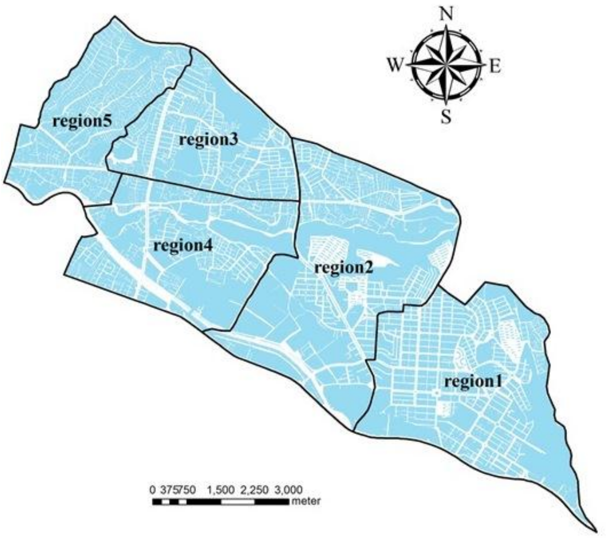

Figure 1. Tabriz zone 1

MATERIALS AND METHODS

In order to assess the vulnerability of road network in study area, the adopted methodological approach considers multi-criteria techniques with the aim of taking into account the different aspects that contribute to recognize vulnerable roads in both regions of formal and informal textures. The first part of the proposed methodology is to select a set of assessing criteria which provides a basis for evaluating the road

[1] Informal settlements refer to: residential areas where a group of housing units has been constructed on land to which the occupant have no legal claim, or which they occupy illegally; unplanned settlements and areas where housing is not in compliance with current planning and building regulations (unauthorized housing). Formal settlements refer to land zoned residential in city master plans or occupied by formal housing (UNEP, 2003).

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network vulnerability. In fact this is the most essential part in the overall debate, because we need to make sure that the selected criteria are sufficient to indicate the overall risk of urban road networks as a mixture function of vulnerability and earthquake hazards.

Since our initial goal was to map the road networks of high risk in the study area, we utilized a set of procedures to standardize and combine data layers to create composite risk maps. Standardization of each data layer to a common set of values was performed using the FUZZY module in the Idrisi32 software (Eastman, 2009). This module is designed to assign each pixel in an image to a fuzzy set by evaluating any of a series of fuzzy set membership functions. The main advantage of this approach for our work is that it avoids setting hard or arbitrarily established thresholds between different levels of risk. It also facilitates subsequent integration of data layers in the generation of composite risk maps, which takes into account the major risk factors for which we have data. The last factor was derived by applying a 7 X 7 frequency filter to rasterized vulnerability segments for which we had crash data. This filter approach essentially counts the number of pixels in the 7X7 kernel so that segments which fill more space (i.e. that are sinuous) receive a higher value in the output raster layer. In addition, we found that 7X7 kernel was sufficiently large to encompass sinuous segments of vulnerability.

Fuzzy Sets are sets (or classes) without sharp boundaries; that is, the transition between membership and non-membership of a location in the set is gradual (Zade, 1965). A Fuzzy Set is characterized by a fuzzy membership grade (also called a possibility) that ranges from 0.0 to 1.0, indicating a continuous increase from non-membership to complete membership. Four fuzzy set membership functions are provided in IDRISI: Sigmoidal, J-Shaped, Linear and User-defined.

We utilized linear fuzzy function at this paper. Integration of the data to create composite risk maps of road network vulnerability was carried out using the Multi-Criteria Evaluation (MCE) module, also in IDRISI. MCE is a decision support tool for Multi-Criteria Evaluation. A decision is a choice between alternatives (such as alternative actions, land allocations, etc.). The basis for a decision is known as a criterion. In a Multi-Criteria Evaluation, an attempt is made to combine a set of criteria to achieve a single composite basis for a decision according to a specific objective, For example, a decision may need to be made about what areas are the most suitable for industrial development. Criteria might include proximity to roads, slope gradient, exclusion of reserved lands, and so on. Through a Multi-Criteria Evaluation, these criteria images representing suitability may be combined to form a single suitability map from which the final choice will be made.

Like the Fuzzy module, the MCE procedure allows for the combination of factors using a variety of functions. We utilized a linear-weighted function, in which factor weights were adjusted incrementally in steps of 0.05 and 0.10. Factor weights are important because they determine how individual factors will trade-off relative to each other. In the case of a linear weighted combination, the higher the factor weight the more influence that factor has on the final composite risk map. We conducted a factor weight sensitivity analysis by varying both the factor weights and the type of fuzzy Function used for each risk factor, thus creating a final set of MCE composite risk maps.

RESULTS AND DISCUSSION

A good logical basis for selecting the criteria is to follow Malczewski's (Malczewski, 1999) recommendation that a criterion is considered good if it is comprehensive and measurable. In the present work we suggest 3 main criteria (with their sub criteria) upon which we base the road network vulnerability assessment. Our selection of these criteria has been based on the framework of assessing vulnerability developed Dr Ahadnejad (Ahadnejad, 2008).

In this study, three available main criteria including: density, level of inclusion and building features are used, which each of these criteria are divided into some sub-criteria and subsequently these criteria are weighted Delphi method. In selecting these criteria we attempt to cover all aspects of possible road network vulnerability. The intended data and layers were collected from census of housing and population in 2011. The weights of criteria and sub-criteria are shown in Table 2.

One of the important criteria in road network vulnerability is roads width. After assessing the roads width of the study area and considering the buildings height, level of inclusion[2] has evaluated. In the next step road network vulnerability from point of density and building features according to deducted weights (Based on Delphi method) has assessed by entering into GIS software (Figures 2,3,4). Ultimately the three main criteria's layer based on their Delphi weights in GIS will be employed to IDRISI software.

Figure 5 shows the results of our analysis for determining the vulnerable roads regarding both formal and informal districts of study area (Regions 1 and 5). As in all risk maps generated, this particular example produces data scaled from zero (no risk) to 1 (maximum risk). In this respect, we divided the obtained results to 5 classes from 1 (minimum vulnerability) to 5 (maximum vulnerability).

One of the unique features of the study area is existence of two opposite districts which are known as formal and informal settlements (regions 1 and 5). According to field studies, the official and also informal tissues were identified. Based on these observations, the north-west side of the study area (Seylab district) is recognized as informal residential area. This tissue is identified as one of the most crowded areas with high rate of building and population density within appropriate roads which are narrow (almost less than 3 meters).

In addition, the absence of spatial planning in construction of buildings of this area has made the condition even worse. Otherwise, the planned or official area (Valiasr town) has been placed in the south-east side. The visual obtained result clearly shows the vulnerable roads. As observed, the most risky road

[2]Estimation of volume of debris of building which surround roads, according to building height and road's width

networks in terms of vulnerability is where, which was identified as unplanned area (Seylab district).

The obtained results also show the importance of planning before construction of a district. However, the Valiasr town (region1) roads as a planned tissue mostly are in low vulnerability condition.

The percentage results in terms of road network vulnerability show that the roads of study area are not greatly in desirable condition. In this respect, the spectrums of very low and low vulnerability jointly are just included 24% of the zone. Meanwhile, according to the diagram, about 46% of the roads are in high and very high risk.

In the following the percentage of road network vulnerability for both region 1 and 5 are shown in Figure7 and Figure8.

Table 2. The obtained weight of main criteria and sub-criteria by Delphi method

Main criteria	Criteria	Sub criteria	Very low	Low	Moderate	High	Very high
			0.2	0.4	0.6	0.8	1
Building features (0.3)	Types of construction material (0.15)	Non-structured	•				
		Steel structure		•			
		Concrete structure			•		
		Brick and iron structure				•	
	Building quality (0.2)	Non-structured	•				
		New built		•			
		Usable			•		
		Need to be repaired				•	
		Need to be refurbished					•
	Building date (0.1)	Non-structured	•				
		Under 10years		•			
		10-20years			•		
		Higher 20years				•	
	Land cover (0.3)	Non-structured	•				
		0-25%		•			
		25-50%			•		
		50-75%				•	
		75-100%					•
	Land use Land use (0.25)	Non-structured	•				
		Low traffic		•			
		Moderate			•		
		High traffic				•	
Density (0.3)	Residential (0.5)	0-75	•				
		75-150		•			
		150-225			•		
		225-300				•	
		+300					•
	Floor area ratio (building density) (0.5)	0-100%	•				
		100-200%		•			
		200-300%			•		
		300-400%				•	
		+400%					•
Level of inclusion (0.4)	Very low (0.2)	-0.3	•				
	Low (0.2)	0.3-0.5		•			
	Moderate (0.2)	0.5-0.7			•		
	High (0.2)	0.7-1				•	
	Very high (0.2)	+1					•

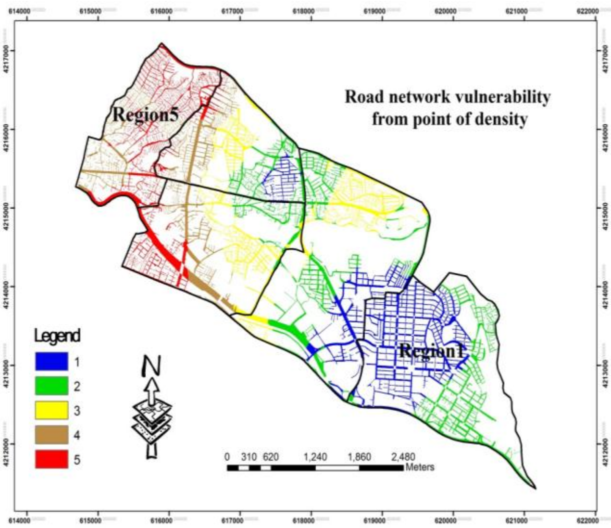

Figure 2. Map of road network vulnerability from point of density in Tabriz zone 1.

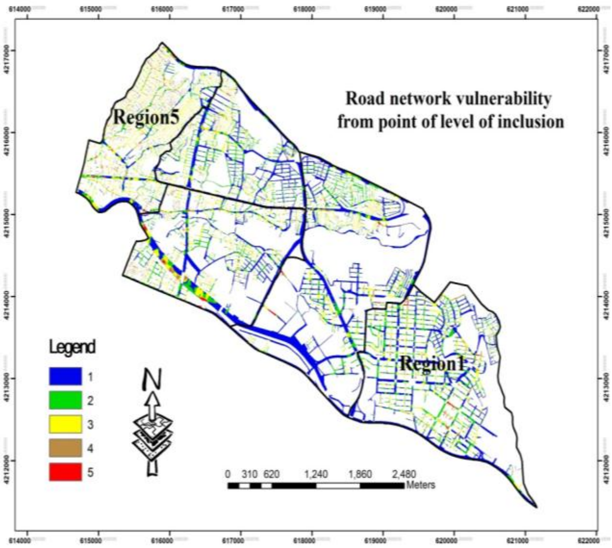

Figure 3. Map of road network vulnerability from point of level of inclusion in Tabriz zone 1

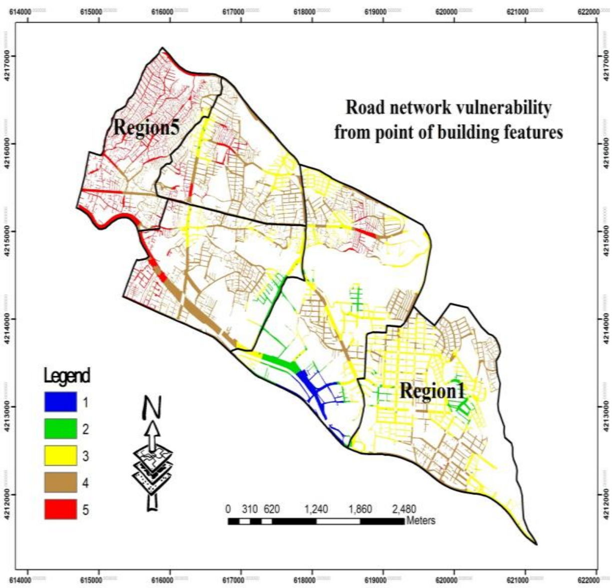

Figure 4. Map of road network vulnerability from point of building features in Tabriz zone 1

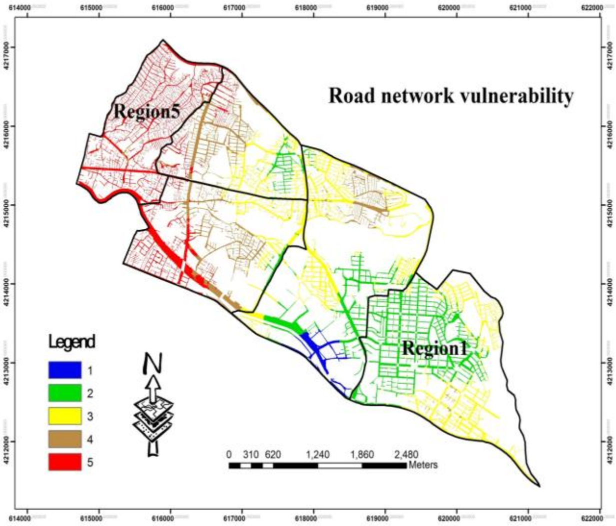

Figure 5. Map of road network vulnerability in Tabriz zone 1

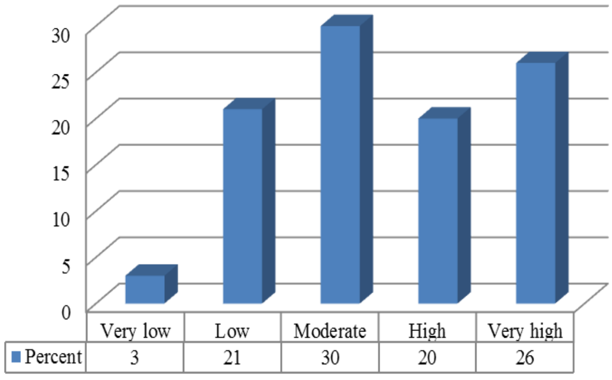

Figure 6. Percentage diagram of road network vulnerability of Tabriz zone 1

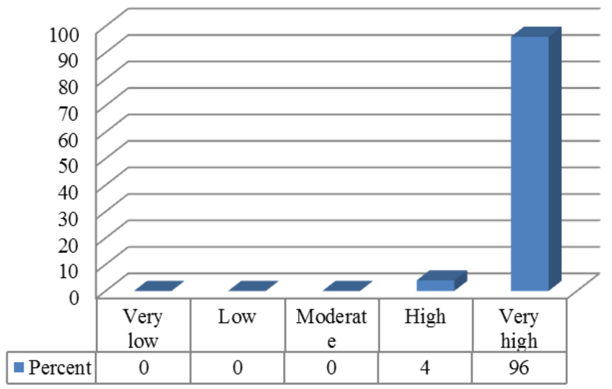

Figure 7. Percentage diagram of road vulnerability of region5

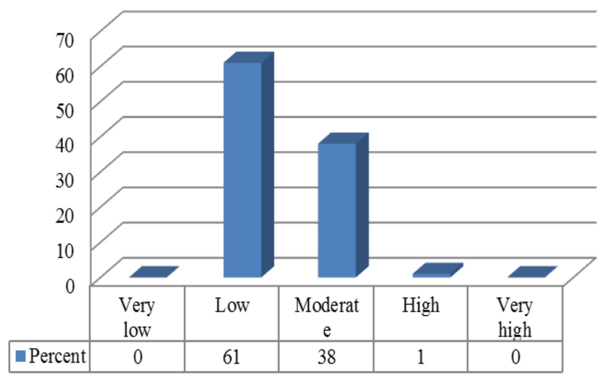

Figure 8. Percentage diagram of road vulnerability of region1

CONCLUSION

Figure 8 shows that 100% of roads in region 5 are in high and very high risk. It's because of the inappropriate conditions which there are in all the slums in the world. On the other hand, Figure8 shows completely vice versa condition in region1which noted the importance of planning.

In the present paper, it became revealed that the roads of region 5 as the informal district of the zone because of some situation such as narrow passages, old neighbourhoods and buildings and… doesn't have appropriate condition in terms of occurring harsh earthquakes and it's resilience is poor while, region 1's roads has different circumstance and this region's roads has almost desirable condition against earthquake.

The obtained result proves that in most cases, natural hazards are not solely the main threat for citizens' health, while lack of attention to plan systematically for human settlements is the most important threat for community health. With appropriate construction, repair, and land use standards, a rebuilt community can be at lower risk to future disasters, compared to pre-disaster conditions. The interrelated phases of disaster management—preparedness, response, recovery, mitigation—consist of coordination between government levels, across local governments, and between public and private organizations in various functional roles and responsibilities.

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