

GIS-BASED ACCESSIBILITY ANALYSIS OF URBAN EMERGENCY SHELTERS: THE CASE OF ADANA CITY

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ABSTRACT:

Accessibility analysis of urban emergency shelters can help support urban disaster prevention planning. Pre-disaster emergency evacuation zoning has become a significant topic on disaster prevention and mitigation research. In this study, we assessed the level of serviceability of urban emergency shelters within maximum capacity, usability, sufficiency and a certain walking time limit by employing spatial analysis techniques of GIS-Network Analyst. The methodology included the following aspects: the distribution analysis of emergency evacuation demands, the calculation of shelter space accessibility and the optimization of evacuation destinations. This methodology was applied to Adana, a city in Turkey, which is located within the Alpine-Himalayan orogenic system, the second major earthquake belt after the Pacific-Belt. It was found that the proposed methodology could be useful in aiding to understand the spatial distribution of urban emergency shelters more accurately and establish effective future urban disaster prevention planning. Additionally, this research provided a feasible way for supporting emergency management in terms of shelter construction, pre-disaster evacuation drills and rescue operations.

1. INTRODUCTION

In urban areas, population and property is concentrated in a small area, and the potential risk of earthquake disaster in these communities is high. Over the past decades, a large number of casualties have resulted from the chaos and confusion of emergency evacuations for unexpected natural disasters worldwide. Reasonable pre-disaster emergency evacuation, therefore, is regarded as a key measure in mitigating calamitous consequences. Emergency evacuation is a complex process that involves rapidly and safely evacuating people to a safe region as far away from the hazard as possible (Mingwu et al., 2012). Urban parks and open green spaces are of a strategic importance for the quality of life of our increasingly urbanised society (Rosa, 2014; Mougiakou & Photis, 2014; Yao et al., 2014). Moreover, parks play an important role in urban disaster prevention and mitigation processes. They play an important role of emergency refuge and the rationality of spatial layout for parks has a direct impact on the comprehensive disaster mitigation benefits.

Urban emergency shelters are referring to open spaces or sites, such as city parks, green spaces, squares, stadiums, school playgrounds and other sites, that can provide a safe refuge, basic life security and rescue for the urban residents when disasters occur. Accessibility analysis of emergency shelters reflects the spatial imbalance of shelters space supply and residents demand. The availability of accessible and attractive emergency shelters is an integral part of urban quality of life (Dou and Zhan, 2011). In recent years, rapid urbanization, unplanned development and rapid population growth has increased pressure on urban green areas. The ever decreasing green spaces have become insufficient to meet public demands in terms of accessibility, spatial distribution and area size. The issue of accessibility is one of the most debated in sustainable urban planning (Unal, 2014).

A study approach was taken to analyse the adequacy of emergency shelters to provide rapid and efficient response to urban earthquakes in Adana. Additionally, the aim was to

identify spatial and planning principles to provide an optimum level of utilisation of urban emergency shelters. In this study, city parks, open green spaces, squares, stadiums and school gardens were selected as the evacuation destinations (shelters). Space accessibility was analysed and researched according to actual urban land use to see if these areas provide safety when a natural disaster occurs. Data was subjected to content analysis to identify the uses associated with the open space network. Afterwards, GIS analysis was undertaken to explore how well the system performs in terms of overlap in governance and diversity.

2. MATERIALS AND METHODS

2.1 Study Area

The study area selected is the City of Adana in Turkey ($37^{\circ}00'N$ $35^{\circ}19'E$). Adana is characterised by a high population density due to people emigrating from neighbouring cities since the 1950s (Akin et al., 2014). The Seyhan River runs through the centre of the city, which is located at the north-eastern edge of the Mediterranean Sea (Figure 1). Urban settlement covers approximately 20,000 hectares (ha) and the population reached more than 2.2 million in 2015 (Turkish Statistical Institute, 2015). Adana consists of four metropolitan districts: Seyhan, Yüreğir, Çukurova and Sarıçam. Cukurova has undergone significant economic development and rapid urban expansion over the past 30 years. Yüreğir district, located east of the river, mainly comprises low-income residential areas and large-scale industries. Sarıçam district lies north and east of Yüreğir. A new residential area and some of the large institutions of the city are in Sarıçam district: Çukurova University, İncirlik Air Base and the Organized Industrial Region.

Turkey lies within the Mediterranean segment of the Alpine-Himalayan orogenic system, which is the second major earthquake belt following the Pacific-Belt. According to the seismicity map of Turkey, 92% of the Turkish land, 95% of the population and 98% of the industry lies on seismically active

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ground. In this century alone, earthquakes in Turkey have caused about 67,000 deaths, 150,000 injuries and destruction of 500,000 structures between 1881 and 1998. The tectonics of Turkey is greatly influenced by the movements of Arabian, Eurasian and African plates (Adalier and Aydingun, 1998).

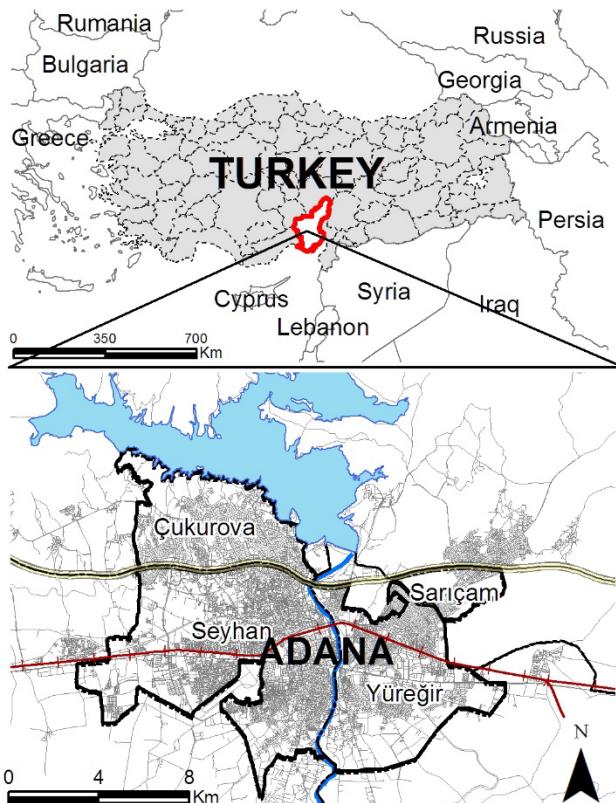


Figure 1. The study area of Adana, Turkey

The region has the tectonic characteristics of the Toros and Southeast Anatolian regions and can be characterised as a fracture zone. In the last twenty years, the biggest earthquake was the Adana-Ceyhan earthquake which occurred on June 27, 1998, with a moment magnitude of 6.3 and a maximum intensity of IX (Destructive) on the European macro seismic scale (Table 1). The total economic loss was estimated at about US\$1 billion. The earthquake killed at least 145 people and left 1,500 people wounded and many thousands homeless in Adana and Ceyhan, the most populous town of the Adana Province. Many villages located between both cities along the Ceyhan River were also affected (Adalier and Aydingun, 1998). Adana and the adjacent areas are under the threat of moderately intense earthquakes. Since there are still many hidden hazards and challenges for urban safety, Adana is in need of evacuation zoning (Figure 2).

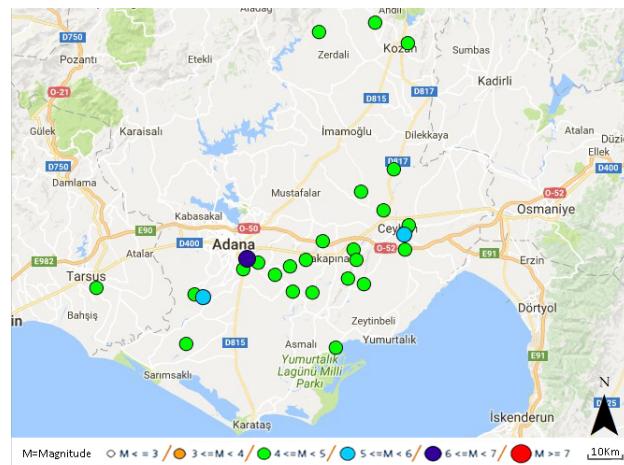


Figure 2. Location of earthquakes in the last two decades

MAGNITUDE	DATE	TIME	LATTITUDE	LONGITUDE	DEPTH	MAGNITUDE
●	31/03/2016	09:33 pm	37.01	35.84	28	4.1
●	02/03/2014	04:25 am	36.73	35.18	25	4.2
●	23/04/2011	05:22 am	37.47	35.58	11	4.0
●	24/07/2009	05:48 am	37.49	35.74	10	4.1
●	22/02/2007	08:49 pm	37.44	35.84	20	4.0
●	18/10/2001	03:50 pm	36.85	35.21	4	4.7
●	15/01/1999	02:04 am	37.05	35.76	35	4.2
●	04/12/1998	04:59 am	36.93	35.54	28	4.0
●	20/09/1998	10:56 pm	36.93	35.40	10	4.0
●	24/08/1998	02:00 am	36.91	35.35	10	4.0
●	15/07/1998	03:32 am	36.88	35.71	12	4.1
●	04/07/1998	09:24 am	36.90	35.44	36	4.2
●	04/07/1998	02:15 am	36.84	35.23	37	5.4
●	28/06/1998	03:20 pm	36.98	35.59	10	4.0
●	28/06/1998	03:59 am	36.92	35.49	21	4.5
●	27/06/1998	09:49 pm	36.73	35.63	10	4.0
●	27/06/1998	08:50 pm	36.86	35.50	10	4.2
●	27/06/1998	06:54 pm	36.96	35.68	20	4.1
●	27/06/1998	02:15 pm	36.93	35.68	8	4.0
●	27/06/1998	02:07 pm	36.86	35.56	15	4.0
●	27/06/1998	04:55 pm	36.93	35.36	10	6.3
●	24/09/1996	04:28 pm	37.15	35.8	10	4.0
●	22/06/1995	05:26 am	36.87	34.92	42	4.4
●	10/02/1994	06:15 am	36.96	35.83	35	4.8
●	03/01/1994	09:00 pm	36.99	35.83	42	5.0
●	25/11/1991	05:42 pm	36.89	35.66	20	4.1
●	07/10/1991	12:29 am	37.09	35.70	10	4.3

Table 1. The history of Adana shows repeated occurrences of earthquakes (<http://www.deprem.gov.tr/>)

2.2 Methodology

This study's methodology consists of six phases (Figure 3):

- Locating the shelter areas (parks, squares and school gardens) gained from survey studies, aerial photography and the Adana city Implementary Development Plan (1/1000 scale).
- Determining the primary standards by referring to literature and expert views.

- Evaluating the quantitative data and calculating the service area of shelter areas.
- Mapping the service areas of shelter areas using the Network Analysis.
- Determining the spatial sufficiency and accessibility potentials of shelter areas.
- Developing suggestions according to final maps.

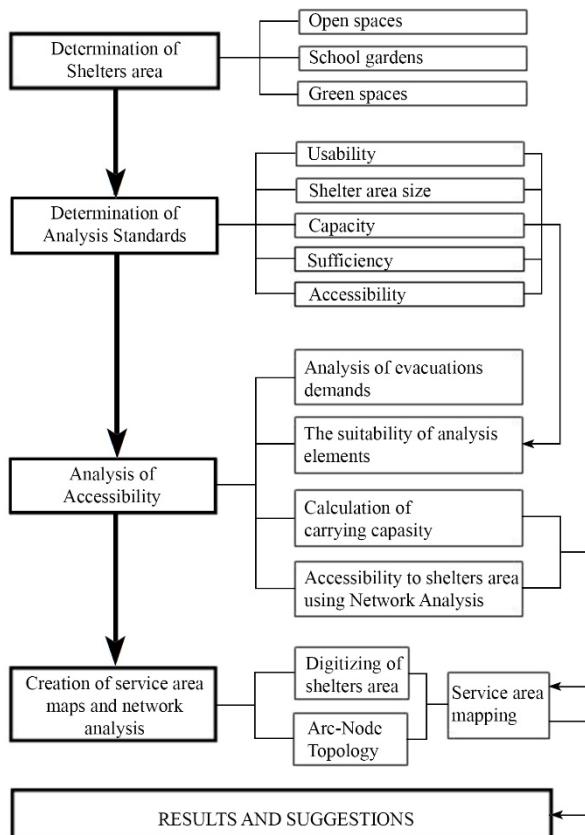


Figure 3. Flow chart of the methodology

2.2.1 Analysis of Evacuation Demands

According to current technology, when and where an earthquake will occur is uncertain. Therefore, the scenario-based methods (disaster assumptions, simulation and prediction) have gradually become the key technological approaches in the field of disaster study: especially in disaster risk assessment and emergency management (Shi et al., 2010; Mingwu et al., 2012). Under the basic idea of scenario analysis and in accordance with the actual requirements of emergency response, a method for evacuation demand is proposed. First, the disaster scenarios can be determined according to the daily regular activity of residents. Previous earthquake incidents show that casualties caused by panic and disorder are more serious when earthquakes occurred at night. Therefore, this paper focuses on the occupant evacuation under a night-time scenario when residents are mainly distributed in the residential areas of the community. Based on the classification of urban areas in terms of population density, the estimate of the spatial distribution of the population under a specific scenario can then be calculated and evacuation demands can be obtained accordingly.

The following assumptions are made:

1. Consider the evacuation procedures when a devastating earthquake has not yet damaged the ground or the earthquake is of a small magnitude.
2. All residents begin to evacuate at the same moment.
3. According to the guidance of emergency managers, residents head towards the pre-specified destinations (shelters), which take the entrance/exit locations into account.
4. Residents are evacuated by foot along the designated routes without consideration of blocked roads and travel speed variations (Mingwu et al., 2012).

2.2.2 Determination of Analysis Elements

The assessment method mainly focused on the size of the areas, usability, capacity, the sufficiency and arrival time (5-, 10- and 15-minutes) to shelter areas (Table 2). This method could be useful in aiding to understand the spatial distribution of urban emergency shelters more accurately and establish effective policies for natural disaster management. The primary indices of shelters' service areas have been identified by specialists' views and literature research. Quantitative and qualitative characteristics of the shelter areas were used for measuring accessibility. In sustainable urban development strategies, users must benefit equally from public services, which are considered an important measure in ensuring the accessibility of social justice (Yenice, 2012; Unal et al., 2016). These considerations, therefore, demonstrate the importance and necessary principles of accessibility. That is, evacuation adscription can be optimised for all occupants in a community in this study. Hence, this research provided a feasible way for supporting emergency management in terms of shelter construction, pre-disaster evacuation drills and rescue operations.

CRITERIA	EVALUATION VARIABLES	DATA AND STANDARD VALUES
Area size	1 st degree	10,000 m ² and above
	2 nd degree	5,000–10,000 m ²
	3 rd degree	1,000–5,000 m ²
	4 th degree	100–1,000 m ²
Usability	Attributes	Existing land-use format (School, green area, etc.)
	Topography	0%–2% almost flat 2%–6% gentle slope 6%–12% moderate slope
	Vegetation	Trees Shrub No vegetation
Capacity	The first evacuation area	Min.1.5 m ² /person
	Tent area	25–35 m ² /family
Sufficiency	Population density	Neighbourhood
Accessibility	Walking time	5 minute 10 minute 15 minute

Table 2. The analysis elements of shelter areas (JICA,2002)

2.2.3 Accessibility Analysis

The stages in the evaluation of the service area are as follows:

First stage: green parks, school gardens and other large open spaces were selected as the evacuation destinations (shelters) to analyse the space accessibility, based on the analysis elements such as moderate vegetation, almost flat or gentle slopes and suitable area size (Su, 2007; Ye et al., 2008; Mingwu et al., 2012).

Second stage: the carrying capacity of each shelter area was calculated by dividing the shelter area to the first evacuation area (min.1.5 m²/person) (Equation 1).

$$S_x \text{ Carrying Capacity} = \frac{S_x \text{ Area Size}}{\text{The first evacuation area size}} \quad (1)$$

where S = Shelter area
 x = Shelter area code

Third stage: to calculate the population density in the 10-minute walking service area of the shelter area, the ratio of the service area intersected with the neighbourhood boundaries was determined. The ‘total service area population (TSAP)’ was calculated by Equation 2.

$$S_x \text{ TSAP} = \sum_{m=1}^M \frac{N_n S_x \text{ Service Area}}{N_n \text{ area}} \times N_n \text{ Total Population} \quad (2)$$

where S = Shelter area
 TSAP = Total service area population
 N = Neighbourhood
 x = Shelter area code

Final stage: the service area for each shelter area was calculated by comparing shelter area carrying capacity to total service area population. These values were calculated by multiplying the optimum walkability time (10 minutes) to obtain the service area for each shelter area according shelter area capacity (Equation 3).

$$S_x \text{ Service Area} = \frac{S_x \text{ Carrying Capacity}}{S_x \text{ TSAP}} \times \text{Walking time} \quad (3)$$

where S = Shelter area
 TSAP = Total service area population
 N = Neighbourhood
 x = Shelter area code

2.2.4 Mapping Accessibility with Using ArcGIS Network Analyst Tool

Accessibility is a broad, flexible and slippery concept (Gould, 1969). The simple definition of accessibility is how fast or far one must go to get there. It indicates the spatial relation between origin and destination or the degree of connection between that location and all others in a region. It is often defined as the relative nearness or proximity of one place to another (Yin & Xu, 2009). For this research, accessibility refers to the physical ease of access to shelter sites by vulnerable populations. This definition also implies the shelter’s outreach capacity in terms of assistance to people who remain in surrounding communities instead of evacuating. To determine accessibility to emergency shelters, certain assumptions are necessary.

The geographic information system (GIS) has been a useful tool for measuring accessibility to urban emergency shelters in terms of supply and demand. Some of the main research fields cover the identification of areas suffering from lack of accessibility due

to many reasons. In recent years, the modelling of accessibility has substantially evolved thanks to enhanced GIS features, particularly the development of GIS modules, such as the ArcGIS Network Analyst Tool, and personal computers’ computational capabilities. There are two common approaches, including the Euclidean Buffer (simple radius methods) and Network Analysis (Nicholls, 2001, Oh & Jeong, 2007, Moseley et al., 2013, La Rosa, 2014).

Previous studies that assessed accessibility to the evacuation destinations (shelters) often employed the so-called ‘simple radius method’ that focuses on the linear distance from shelters rather than considering citizens’ actual routes to them. Moreover, aspects of the surrounding areas of parks, including the number of benefited users, land uses or development density are not considered (Nicholls, 2001, Oh & Jeong, 2007, Unal et al., 2016). The time-based function (Network Analysis) is adopted to select the best evacuation route from assembly points to shelters in this section. Because the Euclidean distance is not applicable for the community emergency evacuation, the actual road network distance is used. Using the network analysis method of GIS, this study analysed the actual accessibility of pedestrians to emergency shelters.

GIS-based network analysis modules, such as the ArcGIS Network Analyst Tool from the ‘Service Area Analysis (Service Area)’, which began with the development of information and computer technology, were used to determine parks’ service areas according to spatial distribution. Centres, arcs, nodes and impediments are key elements in that analysis. Networks occur in segments (Arcs-Nodes), and these segments are defined with the known coordinates of the start and end points. Thus, in the first stage, Arc-Node topology was formed to define the service area. In this research, Arcs are defined pedestrian routes that connect citizens to urban emergency shelters. Impedance refers to barriers that prevent movement between links and different impedance values were assigned according to route types (pedestrian roads, crosswalks, underpasses and overpasses). Therefore, these lengths (walking and crossing roads, underpasses and overpasses) are added in the walking distance and are defined as Arc. Nodes are intersections of links (entrance[s] of the park, crossroads and road intersections). The network extent is line-shaped, so the service areas of urban emergency shelters were determined by 5-, 10- and 15-minute buffers for pedestrian routes within the network. Consequently, it was determined that network analysis could be used to provide the boundaries of the service areas of urban emergency shelters wherein citizens can access them within a given time.

3. RESULTS

The study was conducted for 164 open spaces, 275 school gardens and 333 green areas defined as shelter areas that were determined by survey studies, aerial photography and city plans in Adana. The overall results show the calculations and the mapped service areas with area size, usability, capacity and arrival time.

According to the method mentioned in Section 2.2.1, the spatial distribution of residential population under a night-time scenario was used. As shown in Table 3, the population distribution was not same in each district and ranged from approximately 150,000 to 788,000 people. Additionally, every district showed a vast disparity in terms of the number of the shelter areas, capacity and service areas. The residential buildings and population are so concentrated that if residents evacuated on their own, it would easily cause traffic congestion and slow down the evacuation

procedures. Therefore, it is essential to formulate a reasonable pre-planning strategy to guide the emergency response.

DISTRICT	POPULATION			
	2011	2012	2014	2015
Seyhan	757,928	764,714	779,232	788,722
Yuregir	421,692	416,302	419,240	419,011
Çukurova	326,938	335,733	353,680	359,315
Sarıcam	103,232	111,976	143,547	150,425
TOTAL	1,809,790	1,928,725	2,085,699	2,210,000

Table 3. The population of the four districts of Adana

Referring to the relevant technical standards, the emergent evacuation radius is determined to be 10-minutes walking. By means of the network analysis model in ArcGIS, taking the entrances/exits of each shelter as the centre points and R as the radius, the service areas of shelters were analysed. When R = 10-minutes, the shelters can satisfy the evacuation demands of most of the study area; however, it was selected as the best service radius because the capacity and sufficiency of the shelter area was ignored. Therefore, the shelters' service area was calculated with associated optimum walking distances and the carrying capacity of the shelter area (Equation 3). Equation 3 was applied for each shelter area in the study area.

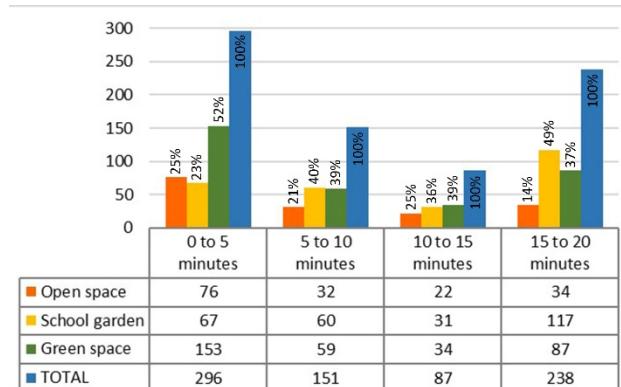


Figure 4: Walking time to shelter area

When the results are evaluated, uneven distribution of shelter areas in terms of capacity occurred at different times. Therefore, the service area ranged from 1 to 20-minute walking area (Figure 4). Most of the shelter areas were 0 to 10-minutes walking time. However, the study area included many shelter areas in which walkability times were 15 to 20 minutes. The carrying capacity of these areas is higher than other areas but they are generally located in the new urban settlements.

As shown in Figure 5 and 6, the shelters in which the arriving time is 10 or 15 minutes are close to crowded settlements. These results showed that the service area of open space, school garden and green spaces (excluding their areas), covered nearly 7,200 ha, 9,400 ha and 8,300 ha respectively. This represents roughly 50%, 67% and 59% of the Adana city centre (13,952 ha), respectively. The main reason for this phenomenon is that the capacity and location of shelters are not aligned with the distribution of the residential population. The results showed that evacuation destinations did not meet the evacuation demands of all residential population in the overcrowded city centre because of the unplanned urban development.

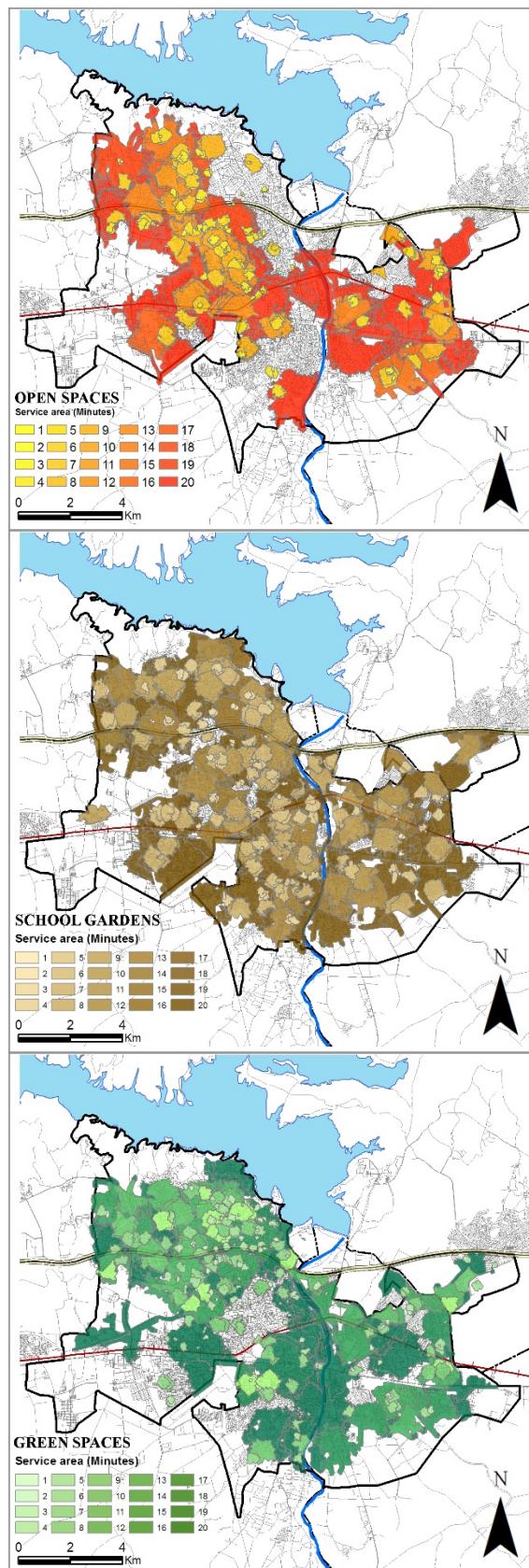


Figure 5: The service areas of shelters

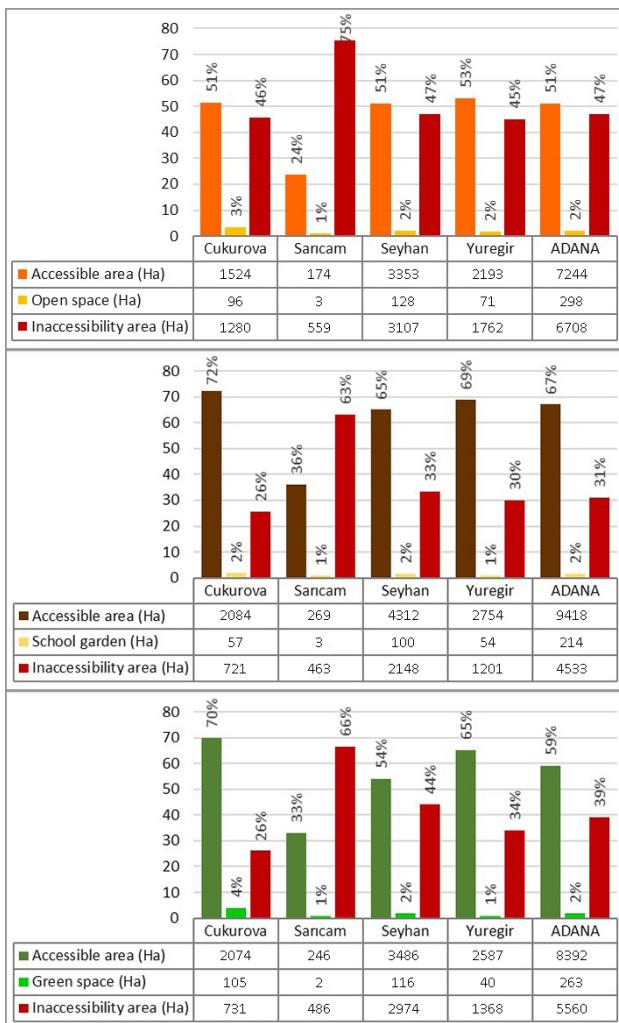


Figure 6: The service area of shelters

In this study, there are two basic problems.

The first problem is whether the population can easily access the safe places?

The evacuation demands were calculated according to the night-time period. Significantly, this study helps to estimate the affected population when one earthquake disaster happens, and according to Figure 7, almost everyone can reach the shelter areas. The accuracy of evacuation needs is obviously improved compared with the even distribution of census data. With respect to evacuation zoning, existing approaches just take distance or capacity into consideration. However, the shelters' spatial accessibility and carrying capacity as key factors can affect evacuation. Thus, this paper proposes to achieve the dual objectives of space accessibility and capacity accommodation. Upon that, evacuation adscription can be optimised for all occupants in a community. Additionally, all of the above algorithms can be conducted by using GIS technology. Consequently, this paper provided a feasible way for supporting emergency management in terms of shelter construction, pre-disaster evacuation drills and rescue operations.

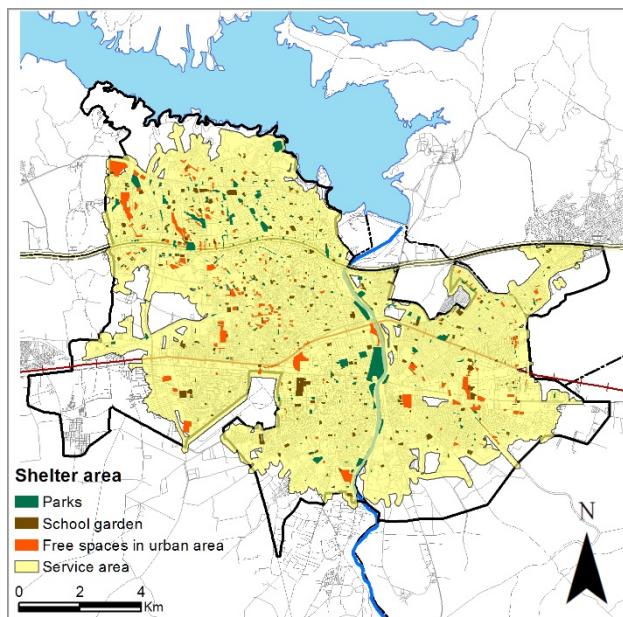


Figure 7: The service area of all shelters

The second major problem was to satisfy basic needs after people access the shelter areas. The analysis incorporates many factors enhancing the suitability of site selection (e.g. shelter areas should be proximal to major roads) (Figure 8). A worst-case scenario where more than half of the inhabitants do not directly benefit from other services (health and food) is possible.

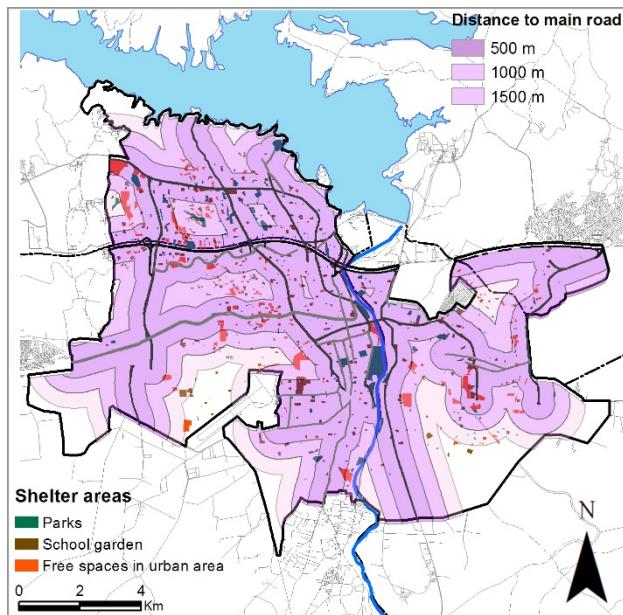


Figure 8: The proximity of major roads

4. CONCLUSION AND DISCUSSION

The main conclusions are as follows:

In this paper, the use of scenario analysis was proposed as a new approach for evacuation demand calculation in terms of distance and capacity.

The study method evaluated the accessibility of green spaces based on walking time, population density, capacity and usability of shelter areas in Adana. The assessment method utilised in this study can be useful in helping to understand the spatial distribution of shelter areas more accurately. It will also establish effective policies for urban park management according to the urban land use and provide a safe area when a natural disaster occurs.

Data was subjected to content analysis to identify the uses associated with the open space network. Afterwards, GIS analysis was undertaken to explore how well the system performs in terms of overlap in governance and diversity.

The realization of shelter areas in accordance with the principles of proper planning is important in terms of the accurate determination of site selection and their relationship with the other utilizations. Shelter areas providing large spaces and diversity can be considered near the borders of the neighbourhood. Thus, many individuals living in different neighbourhoods can benefit from these areas.

This paper focuses on the occupant evacuation under the night-time scenario. The disaster scenarios can be determined according to the regular daily activities of residents. These include daytime/night-time scenario during working days, daytime/night-time scenario during weekends and daytime/night-time scenario during holidays. Based on the classification of urban function areas, the estimate of the spatial distribution of the population under a specific scenario in the study areas can then be calculated and the evacuation demands can be obtained accordingly.

The findings of this study are of particular interest for the planning of human settlements that are prone to earthquakes. It may not be possible to significantly reduce damage to infrastructures, but a balanced shelter area, easy to access and with redundancy of parts and site sizes can help to adapt to and cope with the unexpected changes that occur after a catastrophe.

These findings are also of relevance in the context of developing cities that are undergoing a strong densification process to control and reduce urban sprawl, changing its resilience capacity over time.

The basic problem in Turkey is that no regular access to the shelter areas. Thus, legislation for the planning of shelter spaces should be developed on the basis of scientific studies that consider their functional and social benefits.

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