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Locating Safe Places for Earthquake Temporary Accommodation Using GIS and BWM: Tabriz City

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Abstract

Moving injured and displaced people to safe places soon after an earthquake lowers the human cost of the disaster, but the places must be chosen before it happens. This study identifies safe sites for temporary accommodation in Tabriz, a city close to an active fault. Ten criteria were weighted with the linear Best-Worst Method (BWM) from expert judgments, and the criterion layers were standardized with fuzzy membership functions and combined in ArcGIS 10.8 using fuzzy Sum, Product and Gamma operators. The Gamma 0.9 map gave the most useful separation of sites and was classified into five suitability classes. The south and southeast of Tabriz are the safest areas, while the north is unsuitable because of the fault, high population density and worn-out urban fabric. Several shelters of limited capacity are recommended instead of one large camp.

Keywords: Earthquake, Safe places, Temporary accommodation, Geographic information system, Best-Worst Method, Fuzzy overlay, Tabriz

1. Introduction

Tabriz is a city of about 1.58 million people (2016 census) on 244.5 km², and it lies near one of the most dangerous faults in Iran. The fault has produced devastating earthquakes in the past, so the question of where displaced residents would stay is a practical planning problem. Relief after an earthquake passes through rescue, emergency shelter, temporary accommodation and reconstruction, and the later stages work only if sites were selected correctly beforehand [1].

Earlier Iranian studies located shelters with TOPSIS in Urmia [2], AHP in Mashhad [3] and ANP in Ilam [4]. International work has relied on cause-and-effect models of shelter location [5] and on multi-objective location-allocation [6]. Most weighting methods in this group ask experts to fill a complete pairwise matrix, which is $n(n-1)/2 = 45$ comparisons for ten criteria. BWM asks for only $2n-3 = 17$ comparisons and returns a consistency measure [7].

This study uses ArcGIS 10.8 and BWM together to find safe sites for temporary accommodation in Tabriz. To the authors' knowledge, this combination has not been applied to shelter siting in this city before. The aim is to give urban crisis managers a weighted, map-based basis for deciding where shelters should be built.

2. Methodology

The criteria came from a review of more than 60 papers, theses and books, interviews with experts and local conditions, and ten were retained: distance from the fault, from rivers and floodways, from fuel stations, from green and open spaces, from medical centers, from fire stations, from police stations, population density, slope and geology (soil type). Spatial layers were supplied by urban planning and development organizations.

Experts first named the best (most important) and worst criterion, then rated the best against all others and all others against the worst on a 1 to 9 scale. The weights follow from the linear BWM model [7], solved in LINGO 14.0:

$$\min \xi^L \quad s.t. \quad |w^B - a^{Bj} w^j| \le \xi^L, \quad |w^j - a^{jW} w^W| \le \xi^L, \quad \Sigma w^j = 1, \quad w^j \ge 0 \qquad (1)$$

where w is a criterion weight, a is a pairwise preference, B and W mark the best and worst criteria, and ξL is the objective value, which also serves as the inconsistency measure. In ArcGIS, Euclidean distance rasters were computed for each criterion and rescaled to 0 to 1 with linear fuzzy functions. Safety rises with distance from the fault, rivers and fuel stations (increasing function) and falls with distance from green spaces, medical, fire and police stations, population

density and slope (decreasing function). The fuzzy layers were then overlaid with the Sum, Product and Gamma operators. The Gamma operator is

$$\mu^{\text{Gamma}} = (\Pi \mu^i)^{1-\gamma} \times (1 - \Pi(1 - \mu^i))^{\gamma} \quad (2)$$

with γ between 0 and 1; γ = 0 reproduces the Product and γ = 1 the Sum. Values of 0.7, 0.8 and 0.9 were tested.

3. Results and Discussion

Population density was chosen as the best criterion and slope as the worst. The model gave ξL = 0.079, below the usual threshold of 0.1, so the expert judgments are acceptably consistent. Table 1 lists the weights and fuzzy functions. Density carries the largest weight (0.230), followed by distance from rivers, fuel stations, police stations and soil type (0.105 each); slope has the smallest (0.019).

Table 1. Criteria, BWM weights and fuzzy membership functions

Criterion	Weight	Fuzzy function	Safer when
Distance from fault	0.079	Linear increasing	farther
Distance from rivers and floodways	0.105	Linear increasing	farther
Distance from fuel stations	0.105	Linear increasing	farther
Distance from green and open spaces	0.079	Linear decreasing	closer
Distance from medical centers	0.079	Linear decreasing	closer
Distance from fire stations	0.079	Linear decreasing	closer
Distance from police stations	0.105	Linear decreasing	closer
Population density	0.230	Linear decreasing	lower
Slope	0.019	Linear decreasing	lower
Geology (soil type)	0.105	—	—

The Sum operator raised membership values and put many pixels in the best class, so it is the least selective. The Product operator lowers membership whenever any single criterion is poor and therefore flags a site as unsafe if one hazard is present. Gamma operators lie between the two. Table 2 summarizes the behavior seen in the maps; Gamma 0.9 kept the selectivity of the Product in hazardous zones while still showing open, accessible land, and it was used for the final map.

Table 2. Fuzzy overlay operators and their behavior in the Tabriz maps

Operator	Behavior
Sum	Highest memberships; many pixels in the best class; low sensitivity
Product	Lowest memberships; one high hazard makes a site unsafe
Gamma 0.7 and 0.8	Compromise; darker maps with less contrast
Gamma 0.9	Higher contrast; open, reachable sites with lower hazard stand out

Figure 1 shows the study area and Figure 2 the final map, divided into five classes from completely unsuitable to completely suitable. The south and southeast of Tabriz fall mostly in the suitable classes. The north and center contain the densest districts, and the north also lies on the fault and includes marginal neighborhoods with worn-out fabric, so these areas rate poorly on fault distance, slope and density together.

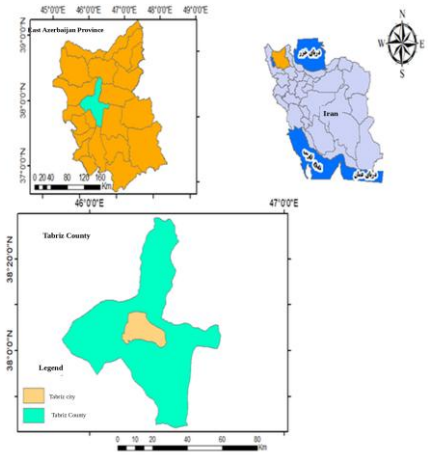


Figure 1. Study area: East Azerbaijan Province, Tabriz County and Tabriz city

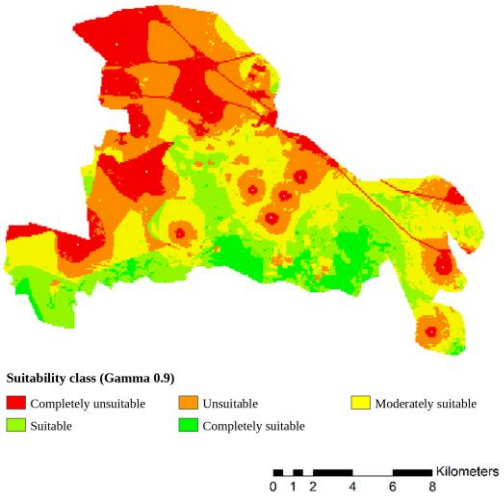


Figure 2. Final suitability map for earthquake shelters (Gamma 0.9)

4. Conclusions

Combining BWM weights with fuzzy GIS overlay gives a transparent way to rank sites for temporary accommodation in Tabriz, with 17 expert comparisons instead of a full pairwise matrix. The Gamma 0.9 map shows that the south and southeast offer the best conditions, and that the north should not be used for shelters because of the active fault. The study recommends several evacuation shelters of at most 25,000 people each, rather than one large camp. Because the city has grown toward the fault, the municipality should limit construction in the north and consider acquiring land in the fault zone. The results depend on the ten criteria and the expert panel; adding road access, building vulnerability and shelter capacity constraints would be natural extensions.

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