Earthquake hazard mapping and analysis by integrating GIS, AHP and TOPSIS for Küçükçekmece region in Turkey

Turan ERDEN, Penjani Hopkins NYIMBILI and Himmet KARAMAN, Turkey

Key words: earthquake hazard analysis, GIS, multi-criteria decision making, AHP, TOPSIS, disaster and emergency management

SUMMARY

Earthquakes and related disasters have persistently caused severe negative impacts on human livelihoods resulting in widespread socio-economic and environmental damage, worldwide. The severity of these disasters have prompted recognition of the need for comprehensive and effective disaster and emergency management (DEM) efforts, which are required to plan, respond to and develop risk mitigation strategies. In this regard, recently developed methods, known as Multi-Criteria Decision Analysis (MCDA), have been widely used in DEM domains by emergency managers to greatly improve the quality of the decision-making process, making it more participatory, explicit, rational and efficient. In the present study, MCDA techniques of the Analytical Hierarchical Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), integrated with GIS, were applied to produce earthquake hazard maps (EHM) for earthquake disaster analysis for a case study region of Küçükçekmece in Istanbul, Turkey. The five main criteria that have the strongest influence on the impact of earthquakes on the study region were determined as: topography, distance to epicentre, soil classification, liquefaction, and fault/focal mechanism. AHP was used to determine the weights of these parameters, which were thereafter used as input into the TOPSIS method and GIS (ESRI ArcGIS) for simulating these outputs to produce earthquake hazard maps. The resulting earthquake hazard maps created by both the AHP and TOPSIS models were compared, showing high correlation and compatibility.

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1. INTRODUCTION

New opportunities have emerged with regard to earthquake emergency planning and management issues that have been stimulated by recent advances in geo-technological fields and Spatial Decision Support Systems (Erden, 2012; Nyimbili and Erden, 2018), with an increasing demand for spatial data, which is now required for complex decision-making by emergency managers involving large numbers of stakeholders across multi-disciplinary teams and criteria. For this, spatial Multi-Criteria Decision Analysis (MCDA) approaches, offering a variety of techniques such as the Analytical Hierarchical Process (AHP) (Saaty, 1980) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981) can be utilized to uncover and integrate decision-makers' preferences with regard to solving GIS-based planning and earthquake emergency management problems.

This study focuses on the application of the GIS-based TOPSIS method, based on previous work done by Erden and Karaman (2012), using the AHP approach, on a case study of the Küçükçekmece region of Istanbul, Turkey. The AHP procedure was used to determine the criteria weights and create an EHM (Erden and Karaman, 2012; Karaman and Erden, 2014). The weights from the AHP procedure were then used in the TOPSIS method to produce another EHM, which was then compared and analysed.

2. BACKGROUND AND RESEARCH CONTRIBUTION

MCDA is a collection of techniques for solving decision-making or evaluating complex problems which have many, conflicting goals and criteria (Voogd, 1982; Zeleny, 1982). The underlying motivation for integrating GIS and MCDA (GIS-based MCDA) emanates from the need to make the capabilities of GIS more relevant for planning and decision-making (Sugumaran and DeGroote, 2011). There are numerous MCDA methods but only two main groups will be considered in this study. These are the techniques using aggregation – the Analytical Hierarchical Process (AHP) developed by Saaty (1980) and the other method using ideal point, known as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) developed by Hwang and Yoon (1981).

The TOPSIS method is based on the concept that the definition of the best alternative is one that should, simultaneously, be closest to (have the shortest Euclidean distance from) the Positive Ideal Solution (PIS) and farthest away from the Negative Ideal Solution (NIS). The final ranking is acquired by means of the closeness index (Sánchez-Lozano et al., 2013). Selected related works highlight application studies of TOPSIS - drought monitoring (Roshan et al., 2016), natural hazards and urban area classification (Najafabadi et al., 2016). State-of-the-art literature survey of the TOPSIS method across wide applications has been conducted by Ferretti (2011) and Behzadian et al. (2012) since the year 1990 and 2000, respectively. The findings reveal that few studies have applied use of TOPSIS in areas of disaster and emergency management, thus presenting a research opportunity within this domain. Ozturk and Batuk (2011) used GIS, AHP and TOPSIS for flood vulnerability assessment in Turkey. GIS, AHP and TOPSIS was used by Çetinkaya et al. (2016) for site selection in South-eastern Turkey.

3. STUDY AREA

Turkey is situated in a region identified with zones of seismicity, making it one of the most seismically active regions in the world (Erdik et al., 1985; Smyth et al., 2004). This study, therefore, focuses on the generation of EHM for the Küçükçekmece region in Istanbul, extending over an area of approximately 36 km^2, as shown in Figure 1.

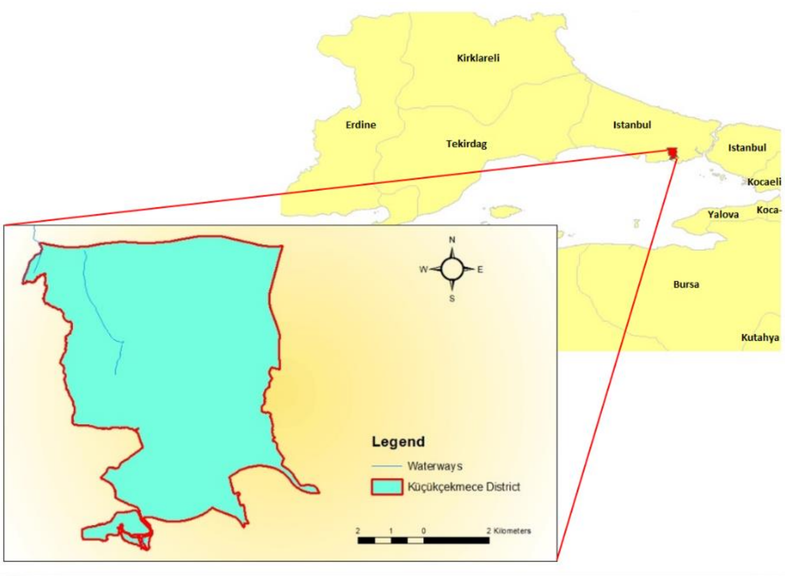

Figure 1 Study area: Küçükçekmece region in Istanbul, Turkey

4. METHODS AND FRAMEWORK FOR THE STUDY

4.1 AHP

AHP (Saaty, 1980) involves breaking down the decision-making problem into a hierarchy of sub-problems. Then, conversion of the subjective evaluations into numerical values and their subsequent processing to rank each alternative on a numerical scale is performed (Rai, 2004) as shown in Table 1.

Table 1 Pairwise comparison scale for AHP criterion evaluation (Saaty 1980)

Intensity of importance	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus

5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance
Reciprocals of above	If activity ***i*** has one of the above non-zero numbers assigned to it when compared with activity ***j***, then ***j*** has the reciprocal value when compared with ***i***

4.2 Topsis

The principal procedures of the TOPSIS technique (Hwang and Yoon, 1981) involves seven steps. First, is the construction of the decision matrix, of a set of alternatives on a given criteria set, consisting of alternatives A_i (*for i = 1, 2, … , n*), criteria C_j (*for j = 1, 2, … , m*) and measures of performance X_{ij} (*for i= 1, 2, …, m; j=1, 2, …, n*) (Rao, 2007), expressed in equation 1.

$$D = \begin{array}{c c} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_m \end{array} & \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \tag{1}$$

The second step involves the normalization of all the elements in the decision matrix to the same dimensionless units so that all possible criteria in the decision problem can be considered by using equation 2 (Rao, 2007; Saaty, 1980).

$$r = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \; i = 1,2, …., m; \; j = 1,2, …., n \tag{2}$$

Calculation of the weighted normalized decision matrix is the third step. The weighted normalized value, V_{ij} , is computed by equation 3.

$$v_{ij} = w_j r_{ij} \,, i = 1, 2, \dots., m, j = 1, 2, \dots, n \tag{3}$$

The fourth procedure is to determine the positive ideal (best) and negative ideal (worst) solutions calculated from the following equations 4 and 5, respectively:

$$A^* = \{v_1^*, \dots, v_n^*\}, \;\; v^* = \{\max(v_{ij}), j \in J; \min(v_{ij}), j \in J'\} \tag{4}$$

$$A^- = \{v_1', \dots, v_n'\}, \;\; v' = \{\min(v_{ij}), j \in J; \max(v_{ij}), j \in J'\} \tag{5}$$

Where J and J’ denote the subsets of beneficial and non-beneficial criteria, respectively. In the fifth step, calculation of the separation measure (distance) for each alternative from the positive and negative ideal solution by the Euclidean distance is done by equations 6 and 7, respectively:

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2}, i = 1, \ldots., m \tag{6}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j'\right)^2}, i = 1, \ldots., m \tag{7}$$

Where V_j* reflects the positive ideal (best) value from among the values of considered criteria for various alternatives, while V_j' indicates the negative ideal (worst) value from among the considered criterion values for different alternatives (Rao, 2007). The sixth step is the computation of the relative closeness to the ideal solution, C_i*. The relative closeness of the alternative, A_i, with respect to A* is given by equation 8.

$$C_i^* = {S_i'}/{(S_i^* + S_i^-)}, \qquad 0 < C_i^* < 1 \tag{8}$$

Lastly, the alternatives are ranked by order of preference from most preferred to the least preferred feasible solutions, which is done by arranging the alternatives in descending order of C_i*. The larger the index value, indicates a good performance of the alternative implying that the best alternative is the one with value of C_i* closest to 1 (greatest relative closeness to the ideal solution) (Dharmarajan and Sharmila, 2016; Malczewski, 1999; Pirdavani et al., 2009).

4.3 Framework for the study

The spatially referenced data, as map layer (evaluation criterion) inputs into a GIS, were combined and processed into the resultant hazard maps (outputs), using both the AHP and TOPSIS techniques. These hazard maps were then compared and analysed. The proposed approach involved the procedures outlined in Figure 2.

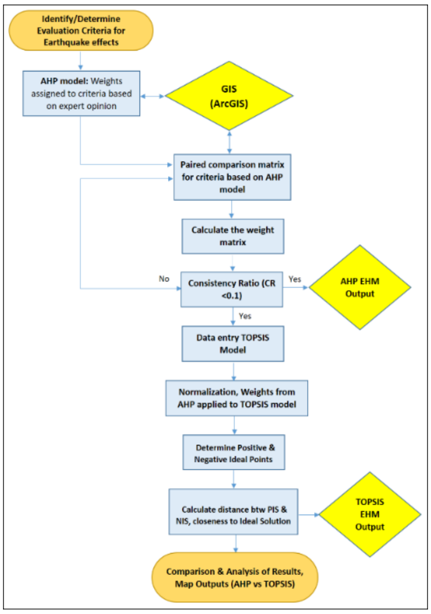

Figure 2 Framework for the study

5. CRITERIA SELECTION FOR EARTHQUAKE HAZARD MAPPING AND ANALYSES

From the study by Erden and Karaman (2012), the main criteria were selected as inputs into the AHP and TOPSIS models, based on the attenuation relation/model. These five main parameters, which were determined for earthquake hazard map creation, were: field topography (FT), source-to-site distance (DS), soil classification (SC), liquefaction potential (LP) and fault/focal mechanism (FM). These criteria are vital for modelling the earthquake hazard effects in a study region, as the effect of the topography amplifies the seismic energy with respect to the height and slope angle; the earthquake effects diminish with increasing distance from the source (epicentre); the site behaviour of earthquake is influenced by the strength of the soil and geological conditions, hence the soil type; the earthquake effects are influenced by the presence of water beneath the soil and the site surface, which is related to the liquefaction potential index and; the assessment of the seismic source zone through an attenuation law which, according to Ambraseys (1995) and Boore (1977), can be described by its geometry and recurrence relationship (Erden and Karaman, 2012; Karaman and Erden, 2014). The value ranges of the criteria/parameters and their matching class values are depicted in Table 2 (Erden and Karaman, 2012).

Table 3 Criteria class value ranges, corresponding class values and their hazard risk levels (Erden and Karaman 2012)

Criteria	**Class Values**			
	1	**2**	**3**	**4**
	No/Low Risk	--→--→	--→--→	Major Risk

1	**FT** (field topography) [*degrees*]	0-10	10-15	15-30	>30
2	**DS** (source-to-site distance) [*km*]	22.21-19.80	19.80-17.38	17.38-14.97	14.97-12.55
3	**SC** (soil classification) [*m/s*]	800-760	760-360	360-180	180-50
4	**LP** (liquefaction potential)	104-103	103-102	102-101	101
5	**FM** (fault/focal mechanism)	0.45-0.53	0.53-0.61	0.61-0.68	0.68-0.76

6. DATA PREPARATION AND GIS ANALYSIS

The pairwise comparison analysis, data preparation and GIS processing procedures for AHP for each of the five criterion map layers were as those applied in the study previously done by Erden and Karaman (2012). For the field topography (FT) criteria, an available digital elevation model (DEM) data of the study area was used as the main input to derive the amplification elements of the topography by creating a *slope raster map*. For the source-to-site distance (DS) criteria, a *distance distribution map* of study region was created from user-generated point shapefile locations of the epicentre (source) as inputs. The *soil map* of the study area, containing numerical values of attribute shear velocity at a depth of 30m was used as input into GIS for the soil classification (SC) criteria. The GIS data input for the liquefaction potential (LP) criteria was the *liquefaction potential map* with attribute data representing numerical values for the liquefaction risk ranging from high (105) to very low/no (101) risk. The fault mechanism (FM) criteria effects were modelled based on the description of the focal mechanism and source-to-site distance exponential using fault line/types, moment magnitude and focal mechanism information factored in the input map layers within the GIS. Each of the five processed criterion map layer inputs were reclassified into the four class values and subsequently used as inputs in the AHP and TOPSIS models for final hazard map generation.

6.1 AHP Model

The weights of each of the five reclassified map layers were derived from the AHP pairwise comparison technique. An overlay of each of the five reclassified raster map layers was multiplied with their corresponding weights resulting in the creation of a weighted hazard output raster map as illustrated in Figure 3.

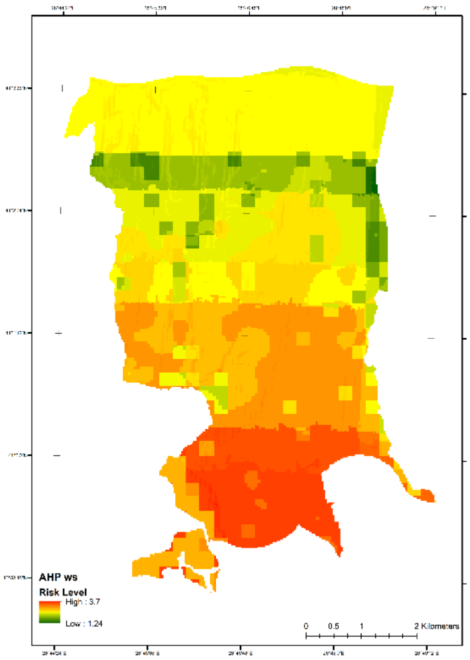

Figure 3 Weighted sum hazard output raster map

6.2 TOPSIS Model

The raw inputs into the TOPSIS model consisted of the five criteria map layers that where already defined and determined. The main calculation procedures, were as outlined in section 4.2. The PIS and NIS for each map criteria was selected based on the desired objective of the study, to map and identify most hazardous areas. Based on this goal, the highest risk level is the ideal point (maximum) and the lowest risk level is the negative ideal point (minimum). The hazard map created from the relative closeness to ideal solution, is as shown in Figure 4.

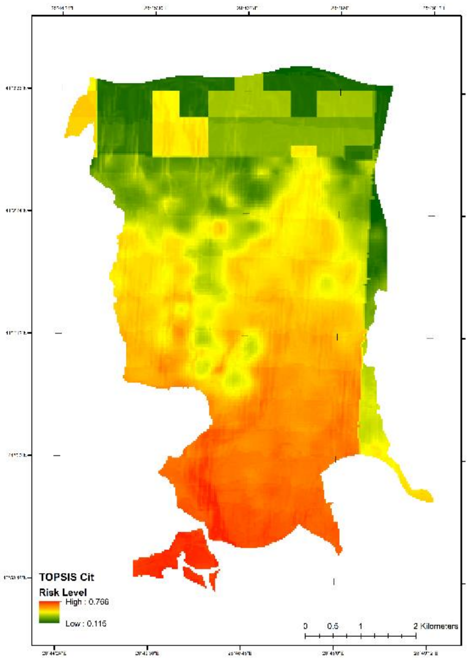

Figure 4 Hazard map output created from relative closeness to ideal solution computation

7. RESULTS AND ANALYSIS

7.1 AHP earthquake hazard map

After the weighted sum analysis process, the weighted sum EHM raster was normalized and reclassified into the 1 to 4 classification, based on associated risk levels and class values, and the resulting AHP earthquake hazard map (EHM) was generated, as shown in Figure 5.

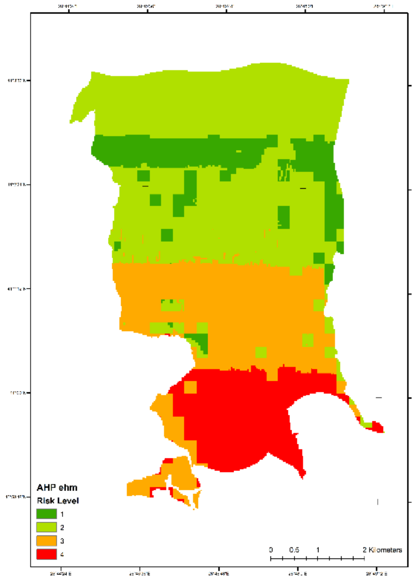

Figure 5 AHP earthquake hazard map (EHM)

7.2 TOPSIS earthquake hazard map

Finally, the preference order was ranked by arranging the map criteria output according to the 1 to 4 classification values, resulting in the creation of the TOPSIS earthquake hazard map, as shown in Figure 6, to be compared and analysed with the AHP map result.

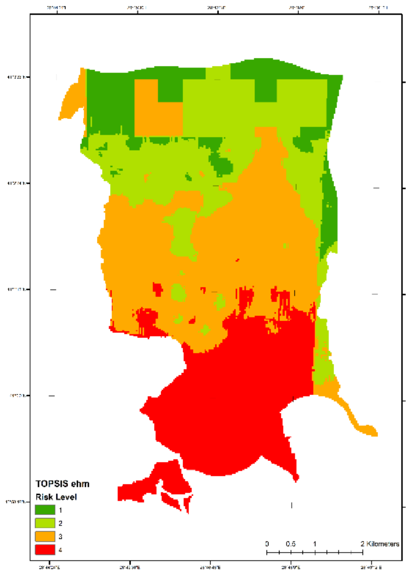

Figure 6 TOPSIS earthquake hazard map (EHM)

7.3 Comparison and analysis of the AHP and TOPSIS earthquake hazard maps

The resulting earthquake hazard maps of the study region, Küçükçekmece, were generated using both MCDA methods of AHP and TOPSIS successfully, achieving our main objective of the study, as shown previously in Figures 5 and 6. As can be observed from Figures 5 and 6, a visual comparison between the AHP and TOPSIS earthquake hazard maps revealed similar patterns of risk level.

By a correlation analysis of the AHP with the TOPSIS map, the correlation coefficient (Pearson's correlation coefficient) was determined as 0.727. This indicated a strong correlation between the two maps, with similar class distribution patterns as inferred from the visual interpretation.

In order to quantify the correlation pattern in each location of the classified study region by risk level with respect to their corresponding risk level class values, a variance analysis was performed on the AHP and TOPSIS maps. The variance analysis compared the variance between the AHP and TOPSIS maps, pixel-by-pixel by spatial location and determined the difference between them as shown in the form of a map output in Figure 7.

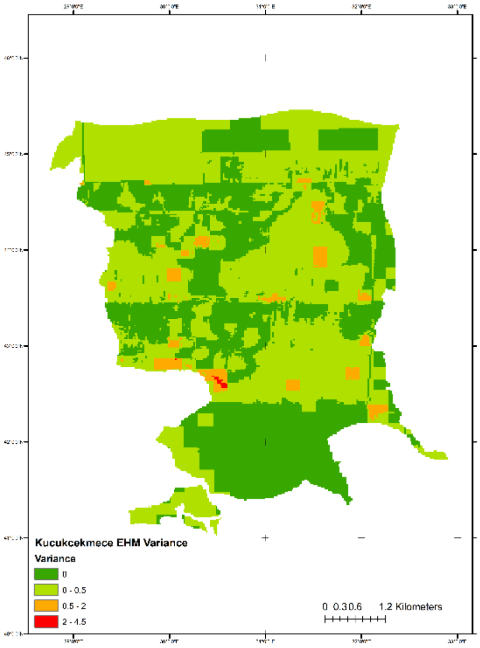

Figure 7 Variance map

8. DISCUSSION

In this study, the MCDA techniques of AHP and TOPSIS were both applied to generate earthquake hazard map results for the case study area of Küçükçekmece in Istanbul. Five main evaluation criteria were determined and used as main inputs for the simulation of earthquake effects in the form of generated hazard maps for both AHP and TOPSIS approaches. From the comparison and analysis of the map outputs in Figures 5 and 6, the results indicated that both maps showed a high correlation and good compatibility based on visual interpretation, correlation computation (Pearson's coefficient of 0.727), variance analysis between the AHP and TOPSIS hazard maps (Figure 7).

Both AHP and TOPSIS hazard map outputs were comparable to each other, demonstrating the increased effectiveness and suitability of the methods integrated with GIS, for conducting earthquake monitoring and disaster management studies. The unique suitability for each of these techniques for use in this study can be discussed. For the AHP method, the reduction of a complex decision problem, such as earthquake hazard mapping, is readily decomposed to make it simpler. The consistency ratio for the weight determination was less than 0.1 (Erden and Karaman, 2012), and this indicated the consistency and robustness of the preferences, thereby increasing the reliability of the resultant AHP and TOPSIS hazard map outputs.

In the TOPSIS approach, according to Pereira and Duckstein (1993) and Malczewski (1996), the technique is much more suited for implementation in raster data structures, such as the raster map data used in our study in the GIS environment for the production of resultant earthquake hazard maps as raster output data. The TOPSIS method eliminates some of the difficulties linked with inter-dependence among attributes, such as the criteria determined and used in our study. It does not make assumption of the preference independence of attributes, i.e., the alternatives that are considered as inseparable bundles, whereas they are assumed otherwise in other methods (Pereira and Duckstein, 1993; Zeleny, 1982). Furthermore, the TOPSIS method is suitable for this study as it has been applied successfully to solve various decision-making problems that include the selection and evaluation of problems with a finite number of alternatives, which is essentially due to its intuitiveness, ease of understanding and implementation. Additionally, TOPSIS has been proven to be one of the best techniques in resolving rank reversal issues and has a robust logical approach that expresses the basis of human preference.

In this study, the extension and use of TOPSIS for DEM problems has arisen, in a large part, from the following reasons and advantages of this technique: employs a robust logic that guides and represents the rationale of human choices; utilizes a scalar value that characterizes both the best and worst alternatives, simultaneously; is a simple computational process, which is easily programmable and integrated in other decision support systems, such as GIS; and the performance measures of all alternatives on attributes can be visualised in a GIS environment (Dharmarajan and Sharmila, 2016). A distinction can be drawn, however, between the AHP and TOPSIS methods in terms of the GIS processing and analysis steps performed using the ModelBuilder application, after criteria selection and the necessary data preparation procedures are done. There are more analysis steps and additional works on the criteria involved in the TOPSIS method as compared to AHP, requiring comparatively longer processing time for hazard map generation.

9. CONCLUSIONS

Past and recent tragic earthquake events in the world have underpinned the increasing need for the development and integration of scientific approaches, such as MCDA techniques with geospatial systems, such as GIS, to support effective DEM. Emergency managers and decision-makers use these tools for simulating disaster effects through visualization for easier interpretation of outputs in the form of hazard maps. In the present study, GIS-MCDA methods of AHP and TOPSIS were implemented to generate earthquake hazard maps of a case study area of Küçükçekmece in Istanbul. To the best of the knowledge of the authors, no other works combining use of TOPSIS have been conducted for this study region, besides the previous study by Erden and Karaman (2012) that this paper builds the work upon. A framework for the study was established from which a design of both AHP and TOPSIS approaches was conducted, starting with a definition of the decision problem, which was our main objective, i.e., to produce earthquake hazard maps for earthquake disasters.

This paper concludes that the earthquake hazard map from the proposed TOPSIS method is comparable to that generated from the AHP method. This validates the usability of the TOPSIS hazard map by emergency managers and planners, alternatively as a base map for providing useful knowledge for evaluation of earthquake risk and planning mitigation activities in the study region. The study results further demonstrated the applicability of the AHP and TOPSIS models for earthquake hazard mapping and DEM studies, despite some limitations that may exist to affect the reliability of outputs with regard to the uncertainties and imprecisions of evaluation criteria and their weights, accuracy, resolution and current nature of the input data. Fuzzy AHP and fuzzy TOPSIS approaches are suggested to improve the accuracy and validity by resolving uncertainties of the input data. Use of other MCDA techniques, such as SAW, PROMETHEE and ELECTRE could be applied to make more comprehensive comparisons with the AHP and TOPSIS maps and to test the robustness of the results for validation. The AHP and TOPSIS framework for hazard mapping and analysis that has been established can be further applied to other disaster types, such as floods, landslides, fires, etc., due to its versatility and simplified approach following the creation of the ModelBuilder application work flow for automating GIS processes for each of the approaches. MCDA techniques, such as AHP and TOPSIS, incorporate the preferences of experts and others involved in emergency management work, thereby reducing the critical decision-making time by minimizing conflicts that could arise in emergencies. Therefore, in order to further reduce the time for analysis of earthquake hazards and to prepare more accurate hazard map outputs, the development of automated techniques and software integration of GIS, AHP and TOPSIS process flows, is highly recommended.

REFERENCES

Ambraseys NN (1995) The prediction of earthquake peak ground acceleration in Europe. Earthquake engineering & structural dynamics 24(4): 467-490

Behzadian M, Otaghsara SK, Yazdani M, Ignatius J (2012) A state-of the-art survey of TOPSIS applications. Expert Systems with Applications 39(17): 13051-13069

Boore DM, Joyner WB, Fumal TE (1997) Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes: a summary of recent work. Seismological research letters 68(1): 128-153

Chen K, Blong R, Jacobson C (2003) Towards an integrated approach to natural hazards risk assessment using GIS: with reference to bushfires. Environmental Management 31(4): 0546-0560

Çetinkaya C, Özceylan E, Erbaş M, Kabak M (2016) GIS-based fuzzy MCDA approach for siting refugee camp: A case study for southeastern Turkey. International Journal of Disaster Risk Reduction 18: 218-231

Dharmarajan R, Sharmila C (2016) The Evaluation of Topsis and Fuzzy-Topsis Method for Decision Making System in Data mining. International Research Journal of Engineering and Technology (IRJET) 3: 9

Erden T (2012) Disaster and Emergency Management Activities by Geospatial Tools with special reference to Turkey. Disaster Advances 5(1): 29-36

Erden T, Coskun MZ (2010) Multi-criteria site selection for fire services: the interaction with analytic hierarchy process and geographic information systems. Nat Hazard Earth Sys 10(10):2127–2134. doi: http://10.5194/nhess-10-2127-2010

Erden T, Karaman H (2012) Analysis of earthquake parameters to generate hazard maps by integrating AHP and GIS for Küçükçekmece region. Natural Hazards and Earth System Sciences 12(2): 475-483

Erdik M, Doyuran V, Akkaş N, Gülkan P (1985) A probabilistic assessment of the seismic hazard in Turkey. Tectonophysics 117(3-4): 295-344

Ferretti V (2011) Integrating Multicriteria Analysis and Geographic Information Systems: a survey and classification of the literature. 74th Meeting of the European Working Group "Multiple Criteria Decision Aiding"

Hwang CL, Yoon K (1981) Methods for multiple attribute decision-making. In: Multiple attribute decision making (pp. 58-191). Springer Berlin Heidelberg

Karaman H, Erden T (2014) Net earthquake hazard and elements at risk (NEaR) map creation for city of Istanbul via spatial multi-criteria decision analysis. Natural Hazards:1-25 doi:10.1007/s11069-014-1099-2

Malczewski J (1996) A GIS-based approach to multiple criteria group decision-making. International Journal of Geographical Information Systems 10(8): 955-971

Malczewski J (1999) GIS and multicriteria decision analysis. John Wiley & Sons

Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. International Journal of Geographical Information Science 20(7): 703-726

Najafabadi RM, Ramesht MH, Ghazi I, Khajedin SJ, Seif A, Nohegar A, Mahdavi A (2016) Identification of natural hazards and classification of urban areas by TOPSIS model (case study: Bandar Abbas city, Iran). Geomatics, Natural Hazards and Risk 7(1): 85-100

Nyimbili PH, Erden T (2018) Spatial decision support systems (SDSS) and software applications for earthquake disaster management with special reference to Turkey. Natural Hazards. 90(3):1485-1507. doi:10.1007/s11069-017-3089-7

Ozturk D, Batuk F (2011) Technique for order preference by similarity to ideal solution (TOPSIS) for spatial decision problems. In: Proceedings ISPRS

Pereira JM, Duckstein L (1993) A multiple criteria decision-making approach to GIS-based land suitability evaluation. International Journal of Geographical Information Science 7(5): 407-424

Pirdavani A, Brijs T, Geert W (2009) A Multiple Criteria Decision Making Approach for Prioritizing Accident Hotspots in the absence of Crash Data. Transport reviews 30(1): 97-113

Rao RV (2007) Decision making in the manufacturing environment: using graph theory and fuzzy multiple attribute decision making methods. Springer Science and Business Media

Roshan G, Ghanghermeh A, Grab SW (2016) Testing a new application for TOPSIS: monitoring drought and wet periods in Iran. Theoretical and Applied Climatology 1-15

Saaty TL (1980) The analytic hierarchy process: planning setting priorities, resource allocation. New York: McGraw-Hill

Sarvar H, Amini J, Laleh-Poor M (2011) Assessment of risk caused by earthquake in region 1 of Tehran using the combination of RADIUS, TOPSIS and AHP models, J. Civil Eng. Urban 1: 39-48

Sánchez-Lozano JM, Teruel-Solano J, Soto-Elvira PL, García-Cascales MS (2013) Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in South-Eastern Spain. Renewable and Sustainable Energy Reviews 24: 544–556

Smyth AW, Altay G, Deodatis G, Erdik M, Franco G, Gülkan P, Yüzügüllü O (2004) Probabilistic benefit-cost analysis for earthquake damage mitigation: Evaluating measures for apartment houses in Turkey. Earthquake Spectra 20(1): 171-203

Sugumaran R, DeGroote J (2011) Spatial decision support systems: Principles and practices. Boca Raton: CRC Press

Voogd H (1982) Multicriteria evaluation with mixed qualitative and quantitative data Environment and Planning B: Planning and Design 9(2): 221-236

Zeleny M (1982) Multiple criteria decision making. New York: McGraw HillAnsal A, Akinci A, Cultrera G, Erdik M, Pessina V, Tönük G, Ameri G (2009) Loss estimation in Istanbul based on deterministic earthquake scenarios of the Marmara Sea region (Turkey). Soil Dynamics and Earthquake Engineering 29(4):699-709

BIOGRAPHICAL NOTES

Turan Erden graduated from Istanbul Technical University (ITU)-Geomatics Engineering in 1998, then completed his MSc in 2001. He worked as a research assistant in Surveying Techniques Division in Geomatics Engineering Department from 1999 until he obtained his PhD in 2009. He has been an Associate Professor in ITU since 2013. He is interested in GIS, Disaster Planning and Management, Spatial Decision Support Systems, Multi-criteria Decision Making and Analysis, Site selection and related subjects.

Publications: Over 26 publications

CONTACTS

Assoc. Prof. Dr. Turan Erden
Istanbul Technical University
Faculty of Civil Engineering, Department of Geomatics Engineering, 34469
Istanbul
TURKEY
Tel. +90 532 666 85 05
Fax + 90 212 285 3833
Email: erdentur@itu.edu.tr
Web site: http://akademi.itu.edu.tr/erdentur/