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EARTHQUAKE HAZARD MAPPING AND ANALYSIS BY INTEGRATING GIS, AHP AND TOPSIS FOR GÖLYAKA REGION IN DUZCE, TURKEY

Keywords: *earthquake hazard analysis, GIS, multi-criteria decision making, AHP, TOPSIS, disaster and risk management*

Absract

Earthquakes and involved hazards are seriously resulted strong adverse effect on human living causing in widespread socia economic and environmental damage, around the worldwide. The intensity of these hazards have conducted identification of the requirement for comprehensive and impressive disasters and risk management efforts (DEM), those are required supposed to layout, counter to and improve the hazard mitigation studies. In this scope, currently advanced approaches, accepted as Multi-Criteria Decision Analysis (MCDA), are widely used in (DEM) ranges by emergency managers to seriously develop the quality of the decision-making process, causing it effective participatory, explicit, rational and efficient. In this 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 used to create earthquake hazard maps (EHM) for earthquake disaster analysis for a case study region of Gölyaka in Duzce, Turkey. The five main criteria which have the strongest effect on the impact of earthquakes on the area studied were classified as: topography, distance to epicentre, classification of soil, liquefaction, and fault mechanism. AHP has been utilized to determine the weights of these parameters, those have been used as input into the TOPSIS method and GIS for imitating those outputs to create earthquake hazard maps. The out come of earthquake hazard maps produced by both the AHP and TOPSIS models have been compared, indicating high correlation and compatibility.

1. Introduction

Some chances have been come into use with related to earthquake hazard planning and administration subjects whick have been exciting by latter improvements in geo-technological areas and Spatial Decision Support Systems [Erden at al.,2018], with an enhancement need for spatial data, that is requested for complex decision-making by hazard conductors concerning huge numbers of participants across multi-disciplinary studies and criteria. In this context, spatial Multi-Criteria Decision Analysis (MCDA) methods, suggesting a different of solutions 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 used to solve and combine decision-makers' choices with related to solving GIS-based planning and earthquake hazard conducting problems. This study concentares on the application of the GIS-based TOPSIS method, based on the using the AHP method, on a case study of the Gölyaka site of Duzce region, Turkey. The AHP approaches was utilized to detect the criteria weights and create an EHM [Erden et al., 2018]. The weights from the AHP process were then utilized in the TOPSIS method to generates another EHM, that was analysed.

2. Materials And Method

2.1. Study Area

The study area is just situated between Ankara and Istanbul; Ankara is 240km away to the East and Istanbul is 228km away to the West. The road of D-100 passes through Duzce and TEM Highway passes around it. Duzce is placed into the plateau of The West Blacksea coast. The city is surrounded to the West by Sakarya, to the Northeast by Zonguldak and to the East by Bolu. The distance from East to West is 23 km and from North to South is 20 km. The city of Duzce is situated in the middle of the plain on a pressure ridge-type hill and is probably tectonically controlled (Fig. 1).

Fig. 1. View of The Study Area

2.2. Methods

2.2.1. AHP

AHP interested in breaking down the decision-making problem into a hierarchy of sub-problems [Saaty, 1980]. And then, conversion of the subjective evaluations into numerical values and their subsequent processing to rank each alternative on a numerical scale is performed as shown in Table 1.

Table 1. Pairwise comparison scale for AHP criterion evaluation [Saaty 1980]

Intensity of Importance	Defination
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

2.2.2. Topsis

The principal procedures of the TOPSIS technique [Hwang and Yoon, 1981] includes seven steps. First, is the construction of the decision matrix, of a set of alternatives on a given criteria set, consisting of alternatives Ai (for i = 1, 2, … , n), criteria Cj (for j = 1, 2, … , m) and measures of performance Xij (for i= 1, 2, …, m; j=1, 2, …, n) [Rao, 2007], expressed in Equation 1.

C C2 C3

$$D=\begin{bmatrix} X11 & X12 \cdots & X1n \\ X21 & X22 & X2n \\ Xm1 & Xm2 & Xmn \end{bmatrix} \quad (1)$$

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 utilizing Equation 2 [Rao, 2007; Saaty, 1980].

$$r=\frac{Xij}{\sqrt{\sum_{i=}^{M} X_{\dot{I}J}^{2}}},\dot{I}=1,2\ldots\ldots\ldots\ldots m;J=1,2,\ldots\ldots\ldots\ldots,n \quad (2)$$

Computation of the weighted normalized decision matrix is the third step. The weighted normalized value, Vij , is calculated by equation 3.

$$vij= wjrij\ ,i=1,2,\ldots,m,j=1,2,\ldots,n \quad (3)$$

The fourth procedure is to determine the positive ideal and negative ideal solutions computed from the following equations 4 and 5, respectively:

$$A*= \{v1*,\ldots,vn*\},\ v*= \{\max(vij),j \in J;\min(vij),j \in J'\} \quad (4)$$

$$A-= \{v1',\ldots,vn'\},\ v'= \{\min(vij),j \in J;\max(vij),j \in J'\} \quad (5)$$

Where J and J' indicates the subsets of beneficial and non-beneficial criteria, respectively. In the fifth step, computation of the separation measure for each alternative from the positive and negative ideal solution by the Euclidean distance is performed by Equations 6 and 7, respectively:

$$S_i^* = \sqrt{\sum_{J=1}^{n}(Vij - V_i^*)^2}\,, i = 1, \dots\dots m \qquad (6)$$

$$S_i^- = \sqrt{\sum_{J=1}^{n}(Vij - V_i')^2}\,, i = 1, \dots\dots m \qquad (7)$$

Where Vj* reflects the positive ideal value from among the values of assumed criteria for diffeent choices, while Vj' denotes the negative ideal value from among the regarded criterion values for different options [Rao, 2007]. The sixth step is the calculation of the relative proximity to the ideal solution, Ci*. The relative proximity of the alternative, Ai, with respect to A* is given by Equation 8.

$$Ci* = Si'(Si* + Si-), 0 < Ci* < 1 \qquad (8)$$

Lastly, the options 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 Ci*. The larger the index value, indicates a good performance of the alternative implying that the best options is the one with value of Ci* closest to 1 (greatest relative closeness to the ideal solution) [Dharmarajan and Sharmila, 2016; Malczewski, 1999; Pirdavani et al., 2009].

3. Criteria Selection For Earthquake Hazard Mapiıng And Analysis

In this study, from the study by Ateş et al. [2015]., the prime criteria were accepted as inputs into the AHP and TOPSIS models, based on the attenuation relation. Supposed four prime parameters, which were obtained for earthquake hazard map creation, were: field topography (FT), source-to-site distance (DS), soil classification (SC), liquefaction potential (LP). These criteria are crucial for modelling the earthquake hazard effects in a investigated region, as the effect of the topography magnifies the seismic energy with regard to the height and slope angle; the earthquake results reduce with improving distance distance from the source around the area threatment of earthquake is affected by the strength of the soil and geological conditions, so the soil type; the earthquake results are affected by the existence of water beneath the soil and the site surface, which is involved to the liquefaction potential index and; the evaluation of the seismic source area through an attenuation creteria which, according to Ambraseys [1995] can be defined by its geometry and recurrence. The value ranges of the parameters and their fitting class values are displayed in Table 2., [Ateş et al. ,2015].

Table 2. Criteria Class Value Ranges, Corresponding Class Values And Their Disaster Risk Levels

Criteria	1	1	3	4
	Low risk	→	→	Mjor Risk
ST (Site topography) [*degrees*]	0-10	10-15	15-30	30>
DS (source-to-site distance) [*km*]	22.21-19.80	19.80-17.38	17.38-14.97	14.97-12.55
SC (Soil Classification)	800-760	760-360	360-180	180-50
LP(liquefaction potential)	104-103	103-102	102-101	101

4. Data Preparation And GIS Analysis

The pairwise comparison analysis, data preparation and GIS processing procedures for AHP for each of the four criterion map layers were as those applied in the study previously done by Ateş et al. [2015]. For the field topography (FT) criteria, an available digital elevation model (DEM) data of the study area was used as the main input to produce the magnification elements of the topography by forming a slope raster map. For the source-to-site distance (DS) criteria, a distance handing out map of study site was created from user-generated point shape file locations of the epicentre as inputs. The soil map of the study site, consisting of numerical values of property shear velocity at a depth of 30 m was used as input into GIS for the soil classification criteria. The GIS variables input for the liquefaction potential (LP) criteria was the liquefaction potential map with property variables representing numerical values for the liquefaction risk ranging from high (100) to very low/no (100) risk. Each of the four operating criterion map layer inputs were recategorized into the four class values and subsequently used as inputs in the AHP and TOPSIS types for final hazard map production.

5. AHP Model

The weights of each of the four recategorized map layers were reproduced from the AHP pairwise comparison technique. An overlay of each of the four categorized raster map layers was breeded with their regarding weights effects in the production of a weighted hazard output raster map as shown in Fig. 2.

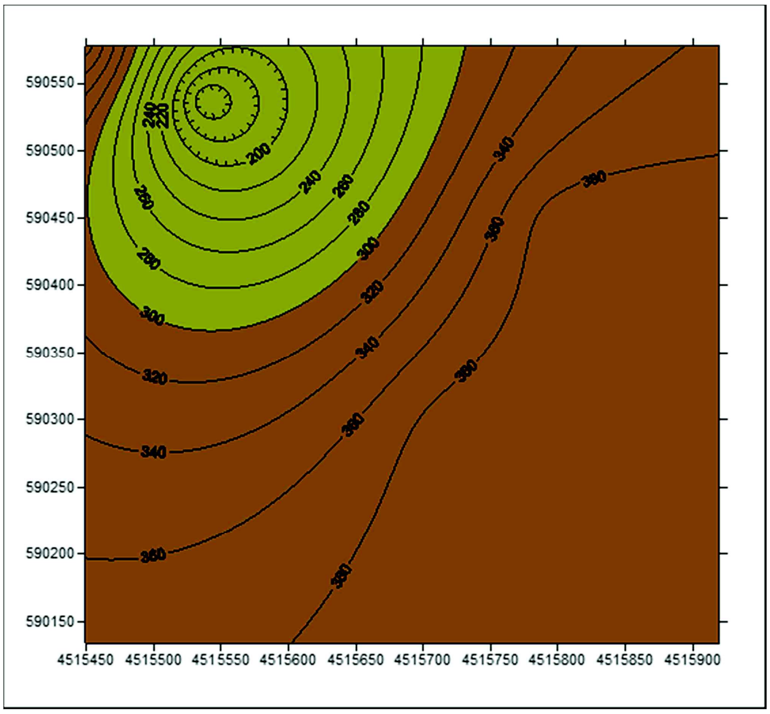

Fig. 2. Weighted Sum Hazard Output Map

6. Topsis Model

The raw inputs into the TOPSIS model containing the four criteria map layers, where already described and detected. The main computaion treatment, were as outlined in section 2.2.2. Based on this purpose, the highest risk level is the maximum point and the lowest risk level is the negative minimum point. The hazard map occured from the relative closeness to ideal solution, is as delineated in Fig. 3.

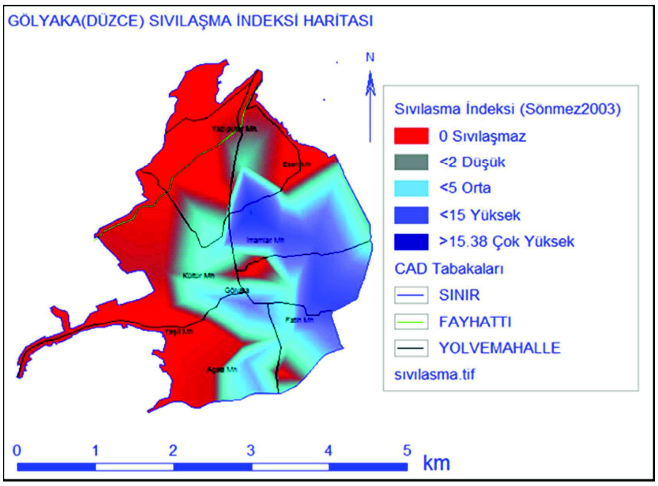

Fig. 3. Risk Map Output Occured From Relative Closeness to Optimum Solution Calculation

7. Results

7.1 AHP Earthquake Risk Map

After the weighted sum analysis treatment, the weighted sum of (Earthquake Risk Map, ERM) raster was normalized and recatogorized into the 1 to 4 classification, based on associated risk levels and class values, and the resulting AHP earthquake risk map (ERM) was produced, as given in Fig. 4 below.

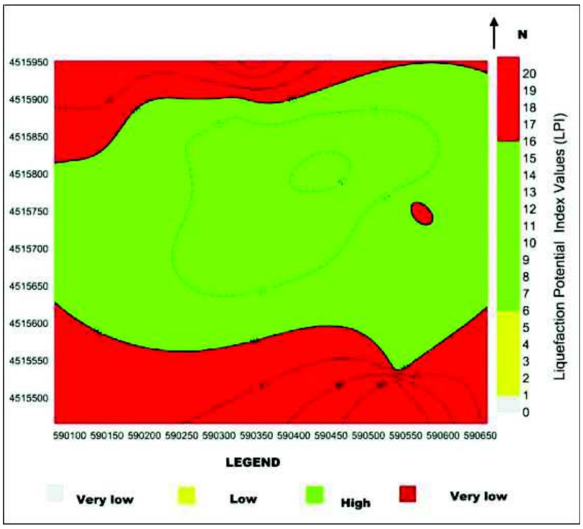

Fig. 4. AHP Earthquake Liquefaction Hazard Map (EHM)

7.2 TOPSIS Earthquake Razard Map

Consequently, the preference order was rowed by collocating the map criteria output according to the 1 to 4 classification values, resulting in the formation of the TOPSIS earthquake risk map, as displayed in Fig. 5 below.

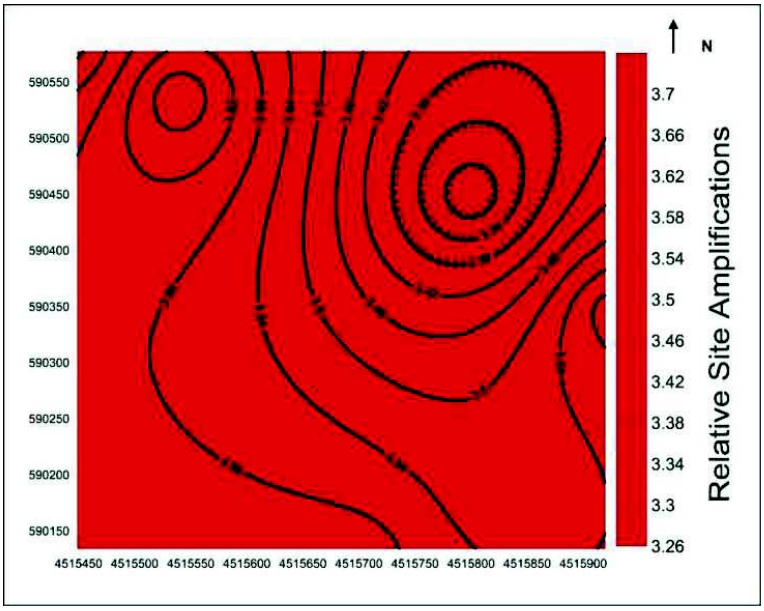

Fig. 6. TOPSIS Earthquake Hazard Map (EHM)

8. Conclusions

Emergency managers and decision-makers conduct these tools for associating hazard results through prediction for easier comment of outputs in the form of risk maps. In this research, GIS-MCDA methods of AHP and TOPSIS were performed to produce earthquake risk maps of a case study area of Gölyaka Duzce in Turkey. To benefit the best of the information of the authors, no other works associating utilize of TOPSIS have been thrated for this research site, further more the previous study by Ateş et al. [2015] that this paper forms the work upon. A framework for the research was formed from that a design of both AHP and TOPSIS procedures was thrated, initiating with a definition of the decision problem, which was important. This study concludes further demonstrated the applicability of the AHP and TOPSIS models for earthquake risk mapping and DEM studies, despite some limitations which could exist to perform the reliability of outputs with respect to the uncertainties and effects of assessment criteria and their weights, accuracy, desicion and current nature of the input data. The AHP and TOPSIS framework for risk mapping and analysis that has been formed can be further performed to other disaster types, such as floods, landslides, fires, etc., due to its versatility and simplified proocedure following the occuring of the Model Builder implementation work flow for automating GIS processes for each of the approaches. MCDA techniques, such as AHP and TOPSIS, associate the preferences of experts and others concerned in emergency management work, so ascending the critical decision-making time by minimizing conflicts which could increase in emergencies. As a result, to further reduce the time for analysis of earthquake risks and to prepare more accurate risk map outputs, the development of automated techniques and software integration of GIS, AHP and TOPSIS process flows, is highly advised.

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