

DOI: 10.24850/j-tyca-2021-02-08

Articles

Flood hazard assessment using AHP in Corum, Turkey Evaluación de peligro de inundación utilizando AHP en Corum, Turquía

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Abstract

In this study, the flood hazard of Corum province, Turkey, was investigated using the Analytic Hierarchy Process (AHP), which is one of the most popular Multi-criteria Decision Analysis (MCDA) methods, based



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on Geographic Information System (GIS). As a result of the AHP process, Corum province was categorized into five flood hazard classes: very high, high, medium, low, and very low. It was determined that 3 % of the total area is under a very high flood hazard, and 25 % is considered a high flood hazard. To assess the validity of the flood hazard map, the results were compared with the historical flood inventory. Our hazard map was compatible with the historical flood inventory, and our hazard map can now be used to estimate the areas that are threatened by possible floods. When the existing structural measures are overlapped with the hazard map in Corum, it is understood that a large part of the structural measures carried out to date have focused on the areas of very high and high flood hazard in the flood hazard map. Future structural measures and detailed studies should now address other areas identified as under threat in the flood hazard map. Our results suggest that the hazard assessment based on MCDA is suitable for flood hazard mapping.

Keywords: Flood, hazard map, analytic hierarchy process, multi-criteria decision analysis, geographic information system, Corum.

Resumen

En este estudio, el peligro de inundación de la provincia de Corum, Turquía, se investigó utilizando el Proceso de Jerarquía Analítica (AHP), que es uno de los métodos más populares de Análisis de Decisión de Criterios Múltiples (MCDA), basado en el Sistema de Información Geográfica (GIS). Como resultado del proceso AHP, la provincia de Corum se clasificó en cinco clases de peligro de inundación: muy alta, alta, media, baja y muy baja. Se determinó que el 3 % del área total está bajo



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un peligro de inundación muy alto, y el 25 % se considera un peligro de inundación alto. Para evaluar la validez del mapa de peligro de inundación, los resultados se compararon con el inventario histórico de inundaciones. Nuestro mapa de peligros era compatible con el inventario histórico de inundaciones; así, dicho mapa de peligros ahora se puede usar para estimar las áreas que están amenazadas por posibles inundaciones. Cuando las medidas estructurales existentes se superponen con el mapa de peligro en Corum, se entiende que una gran parte de las medidas estructurales llevadas a cabo hasta la fecha se han centrado en las áreas de peligro de inundación muy alto y alto en el mapa de peligro de inundación. Las medidas estructurales futuras y los estudios detallados ahora deberían abordar otras áreas identificadas como amenazadas en el mapa de peligro de inundación. Nuestros resultados sugieren que la evaluación de peligros basada en MCDA es adecuada para el mapeo de peligros de inundación.

Palabras clave: inundación, mapa de peligro, proceso de jerarquía analítica, análisis de decisiones de criterios múltiples, sistema de información geográfica, Corum.

Received: 06/08/2018

Accepted: 25/06/2020

Introduction



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Floods are natural, regular phenomena, and they occur when water flow exceeds the capacity of the stream cross-section as a result of excessive rain and/or snowmelt (Murck & Skinner, 2016; Loucks & Van Beek, 2017). In addition to climatic effects, other factors that make a region susceptible to flood include the topographic structure, soil and ground condition, landuse policies, and drainage network (Zevenbergen *et al.*, 2010; Jha, Bloch, & Lamond, 2012).

The increase of urbanization along rivers and floodplains, land-use change, invasive industrialization, and climate change have been identified as key factors that alter the hydrological balance and to increase flood hazard (Zhu, Lund, Jenkins, Marques, & Ritzema, 2007; Huong & Pathirana, 2013; Kundzewicz & Stoffel, 2016).

There are many non-structural and structural measures that can be applied to help prevent or reduce floods, but first, flood hazard maps should be produced (Price & Vojinovic, 2008; Jonkman, Gerritsen, & Marchand, 2012). All prevention and mitigation measures should be designed on the basis of this information (Zevenbergen *et al.*, 2010). Flood hazard maps are classically presented by mapping the boundaries of historic floods that have been experienced before, and these areas are considered to be areas of potential flood hazard in the future (National Research Council, 1996; Babister, McLuckie, Retallick, Askew, & Toniato, 2016). This approach has been successful in terms of presenting the current situation inventory, but it is not sufficient to make forecasts for the future through only the current inventory (United Nations, 1976;



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National Research Council, 1983; Babister et al., 2016). An alternative approach is flood hazard prediction based on hydraulic and hydrological models. Hydraulic and hydrological models are mainly based on determining the level of water depending on the geometry and hydrologic/hydrological conditions of the stream channel, and the highest flow determined according to certain flood return periods (Moel & Aerts, 2008; Mai & De-Smedt, 2017). Hydraulic and hydrological models require large-scale, and high-resolution data, such as length-section and crosssection of the stream to obtain channel geometry (Simonovic, 2013; Ezz, 2018; Khalfallah & Saidi, 2018), and to obtain these data is generally time-consuming and costly (Stefanidis & Stathis, 2013). Also, the possible flood magnitude over a certain time period cannot be fully predicted, and therefore, the problem contains significant uncertainties. Due to the complex nature of the flood occurrence, potential floods need to be addressed not only according to previous flood and meteorological data, but also based on numerous evaluation criteria based on knowledge, expert opinions, views, foresight, and experiences (De-Brito & Evers, 2016).

In recent years, flood hazard mapping studies based on Multi-criteria Decision Analysis (MCDA) are being increasingly used (Papaioannou, Vasiliades, & Loukas, 2015; De-Brito & Evers, 2016; Sakieh, 2017; Xiao, Yi, & Tang, 2017). In particular, the development of software that can be integrated with Geographical Information Systems (GIS) and/or the adaptation of the MCDA methods to GIS software, allows the spatial analyzes based on MCDA to be done rapidly. In this context, several MCDA methods have been integrated with GIS (Linkov & Moberg, 2011; Malczewski & Rinner, 2015; Zhu, 2016), such as the Simple



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Weighted Sum Method, Weighted Product Method, Analytic Hierarchy Process (AHP), Value/Utility Function Approach, TOPSIS, ELECTRE, and PROMETHEE (Malczewski, 1999a; Bao, Ruan, Shen, Hermans, & Janssens, 2012; Malczewski & Rinner 2015). Of these methods, AHP is one of the most widely used methods in the literature and has a common application area in flood studies (Sinha, Bapalu, Singh, & Rath, 2008; Fernandez & Lutz, 2010; Stefanidis & Stathis, 2013; Siddayao, Valdez, & Fernandez, 2014; Ouma & Tateishi, 2014; Nivolianitou, Synodinou, & Manca, 2015; Papaioannou *et al.*, 2015; Lyu, Sun, Shen, & Arulrajah, 2018). AHP is based on the principle of carrying out a decision analysis using multiple factors, such as in other MCDA methods. However, unlike other methods, all factors are compared with each other to perform a pairwise comparison, and the consistency ratio (CR) is used to control the consistency of these pairwise comparison judgments (Saaty, 1980; Malczewski, 1999b).

Corum (Turkey) is a province with many rivers and has experienced important floods in the past. The flood hazard of Corum has been addressed by several scientific studies in recent years. Erdede and Öztürk (2016) determined the flood potential using morphometric indices derived from the Digital Elevation Model (DEM). Yüce and Ercan (2015), and Ercan, Yagci, Yilmaz, Yuce and Unsal (2019) did not focus directly on determining the flood hazard, but modeled the rainfall-runoff relationship, which is related to flood hazard. Kaya and Akdemir (2019) pointed out the urban morphology and residential sites where flood hazard is high. These studies do not examine the entire Corum, do not evaluate multiple factors contributing to flood occurrence, and do not produce a flood hazard map.



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Here we describe the flood hazard situation in Corum by preparing a flood hazard map using AHP and investigate the compatibility of existing flood protection measures with hazardous locations. The first stage of the study involved the creation of a flood hazard map and proving the effectiveness of the AHP method in flood hazard mapping by comparing the hazard map with the historical flood inventory. The second step of the study is based on the examination of the existing structural measures (upstream measures and downstream measures-shore protection structures) in hazardous areas.

Study area: Corum

Corum is located in the inner part of the Central Black Sea Region in Turkey (Figure 1). Corum, consisting of 14 districts, covers an area of 12 820 km² and the average elevation from the sea level is 801 m. Generally, the summers are hot and dry, and the winters are cold and rainy (Corum Governorship, 2017). The spring is short, and the autumn is long. The hottest months are July and August, and the coldest months are January and February. The annual average temperature is 10.8 °C, and the annual total precipitation is 432.2 mm (during the period from 1929 to 2019) (Turkish General Directorate of Meteorology, 2020). According to the data



of the Turkish Statistical Institute, in 2019, the total population of Corum was almost half a million inhabitants (Turkish Statistical Institute, 2020).

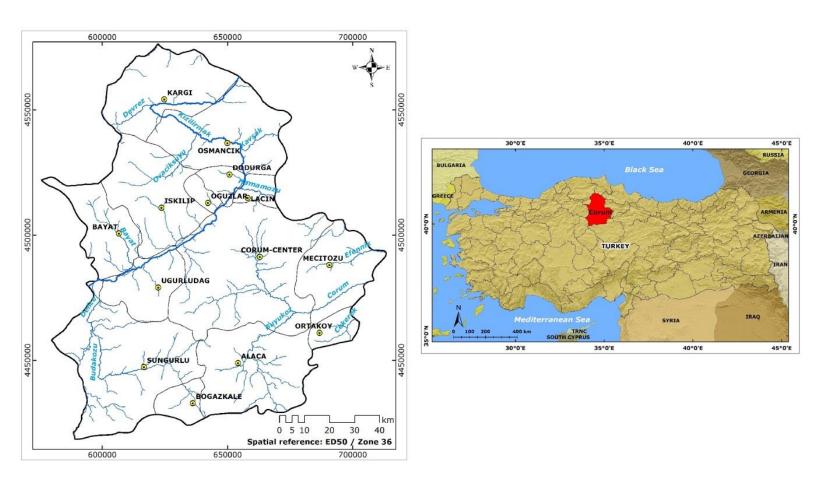


Figure 1. Study area: Corum, Turkey.

Corum province has an area of 8 500 km² in the Kizilirmak Basin, and the other part is in the Yesilirmak Basin (Corum Governorship, 2017). The main streams of Corum province are Kizilirmak, Delice, Devrez, Ovaciksuyu, Bayat, Kavsak, Hamamozu, Budakozu, Corum, Buyukoz, Efennik, and Cekerek (Kaygın & Güven, 2013). Many floods have been experienced to date due to the fact that many streams are located in



Corum, and many settlements have been built around these stream beds. Corum is expected to flood again in the future.

Despite the fact that there were many floods in Corum, only very limited data on the historical flood inventory could be obtained. This is because only the floods that caused very serious damage were recorded in the reports. Unfortunately, it has been observed that very few of the floods experienced are spatially represented by coordinates. The reports generally describe the floodplains as the general region description only (without coordinates, not as spatial data) and do not give a value regarding the magnitude of the flood. However, considering the amount of damage caused by floods from the reports, it was understood that floods were more frequent and caused more damage in Corum-Center, Sungurlu, and Osmancik compared to other districts (Turkish General Directorate of State Hydraulic Works, 1998; Turkish General Directorate of State Hydraulic Works, 2017).

Data and methods

AHP was used in the determination of the flood hazard of Corum. AHP, developed by Saaty in the 1980s for complex decision problems, is based on the evaluations of multi-criteria and a problem is modeled in a hierarchical system at the level of main target, criteria, sub-criteria and



options in this method (Saaty, 1980; Malczewski, 1999b). In AHP, weights are determined by pairwise comparison. In addition, according to the nature of the decision problem, pairwise comparisons can be used to obtain the relative importance values of options for a criterion. By using the criterion weights and the option values for each criterion (the importance of the options relative to each other), the AHP analysis value for each option is calculated as in Equation (1) (Saaty & Vargas, 2012):

$$A_{AHP} = \sum_{i}^{n} a_{ij} w_{i} \tag{1}$$

Where a_{ij} is the value of option i for criterion j (relative importance to other options), and w_j is the weight of criterion j determined by pairwise comparison. The important point is that the weights of the criteria should be normalized to be the sum of 1, and that the criteria layers (pixels or vectors —polygons, lines, points— with options) should have standardized values in the same value range (Malczewski, 1999b).

In the first step of the study, the factors causing the flood were determined, and the decision hierarchy was established, then the weights of criteria and the sub-categories/grouped options were calculated using pairwise comparisons. For criteria with numerical values that have linearly increasing or decreasing significance levels, pairwise comparison was not required. To obtain the standard criteria layers required for all the criteria to be processed together, normalization was performed for all the criteria.

The flood hazard map obtained as a result of the AHP decision analysis, covering Corum with all districts, was separated into five levels of hazard and the locations of the existing structural measures of flood



control were overlapped with this map to examine whether there are structural measures in the areas where flood hazard is important. The workflow showing the main steps of the study is shown in Figure 2.

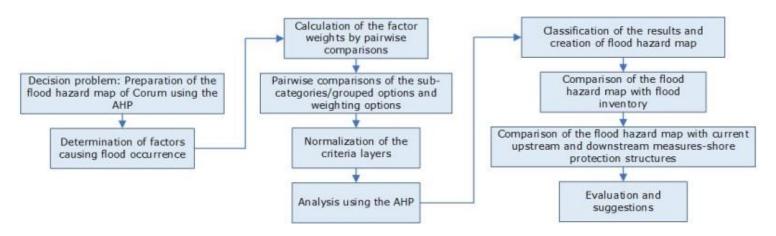
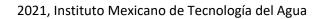


Figure 2. Workflow of the study.

The data and technical specifications used for the preparation of the criteria layers and analyses in the study are shown in Table 1. Processing of the data and multi-criteria decision analysis, based on AHP, was performed using ArcGIS 10.0 software. The sub-basins and drainage networks were obtained from a DEM using ArcGIS and the Arc Hydro tool.

Table 1. Data and technical specifications.

Data (date)	Scale/resolution	Source





Aster GDEM (2011)	1 Arc-Second	USGS Earth Explorer
Precipitation (long- term average, up- to-date)	1/100 000	Turkish General Directorate of Meteorology
Geology (up-to- date)	1/100 000, 1/500 000	Turkish General Directorate of Mineral Research and Exploration
Flood protection structures (up-to- date)	1/1 000, 1/5 000, 1/25 000	Turkish General Directorate of State Hydraulic Works
Land use/cover (2012)	100 m pixel size	European Environment Agency
Landsat OLI (2018)	30 m pixel size	USGS Earth Explorer



Determination of factors

The determination of the factors causing flood occurrence is important in terms of assessment of the flood hazard and is the first step in the production of flood hazard maps. For this reason, the factors must be determined in such a way as to fully characterize the problem. In the present study, the literature survey (Yalcin & Akyurek, 2004; Sinha *et al.*, 2008; Fernandez & Lutz, 2010; Stefanidis & Stathis, 2013; Siddayao *et al.*, 2014; Ouma & Tateishi, 2014; Xiao *et al.*, 2017), the characteristics of the study area, and data accessibility and availability were taken into account, and the factors were determined as a) precipitation; b) land use/cover; c) Geology; d) elevation; e) Slope; f) aspect; g) distance to rivers; h) size of sub-basins, and i) shape of sub-basins.

Determination of criteria weights

Weights were determined using the pairwise comparison method, and the AHP preference scale in Table 2 was used in these comparisons. Based on



this preference scale, all factors were compared in pairs in the range of 1-9. How important a factor is in comparison to the other was decided based on the literature survey, and the numerical value expressing this degree of importance was determined using Table 2. The pairwise comparison matrix of the factors is shown in Table 3.

Table 2. AHP preference scale (Saaty, 1980).

Definition	AHP scale
Equal importance	1
Item 1 is slightly more important than item 2	3
Item 1 is more important than item 2	5
Item 1 is very strong important relative to item 2	7
Item 1 is extremely important relative to item 2	9
	2, 4, 6, 8 intermediate values
	1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9 reciprocal values

Table 3. Pairwise comparison matrix.



Criterion	C1	C2	С3	C4	C5	C6	С7	C8	С9
C1	1	2	3	4	5	5	6	6	6
C2	1/2	1	3	4	5	5	6	6	6
С3	1/3	1/3	1	2	3	3	4	5	6
C4	1/4	1/4	1/2	1	2	2	4	5	6
C5	1/5	1/5	1/3	1/2	1	2	3	4	5
C6	1/5	1/5	1/3	1/2	1/2	1	2	3	4
C7	1/6	1/6	1/4	1/4	1/3	1/2	1	2	3
C8	1/6	1/6	1/5	1/5	1/4	1/3	1/2	1	2
С9	1/6	1/6	1/6	1/6	1/5	1/4	1/3	1/2	1

C1: Precipitation, C2: Distance to rivers, C3: Slope, C4: Elevation, C5: Land use/cover, C6: Geology, C7: Aspect, C8: Size of sub-basins, C9: Shape of sub-basins.

To obtain the relative weights of the criteria, as a total weight of 1, column sums are taken in the pairwise comparison matrix, and each value is divided by the column sum. The relative weights are then calculated by averaging each line (Table 4).

Table 4. Weight calculation.



Criterion	C1	C2	С3	C4	C5	C6	С7	C8	C9	Weights
C1	0.335	0.446	0.342	0.317	0.289	0.262	0.224	0.185	0.154	0.284
C2	0.168	0.223	0.342	0.317	0.289	0.262	0.224	0.185	0.154	0.240
С3	0.112	0.074	0.114	0.159	0.174	0.157	0.149	0.154	0.154	0.138
C4	0.084	0.056	0.057	0.079	0.116	0.105	0.149	0.154	0.154	0.106
C5	0.067	0.045	0.038	0.040	0.058	0.105	0.112	0.123	0.128	0.079
C6	0.067	0.045	0.038	0.040	0.029	0.052	0.075	0.092	0.103	0.060
C7	0.056	0.037	0.028	0.020	0.019	0.026	0.037	0.062	0.077	0.040
C8	0.056	0.037	0.023	0.016	0.014	0.017	0.019	0.031	0.051	0.029
С9	0.056	0.037	0.019	0.013	0.012	0.013	0.012	0.015	0.026	0.023
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

The consistency ratio was calculated to determine the consistency of the pairwise comparison judgments. For this purpose, weights and each line of the pairwise comparison matrix are multiplied and added. These values are then divided by weights. By taking the average of these values, the average value of the consistency vector, λ , is calculated. Then the consistency index, CI, is calculated according to Equation (2). In this equation, n is the number of criteria. The consistency ratio, CR, is calculated by dividing the CI by the RI Randomness Index (Table 5), which varies depending on the number of factors to be compared, as indicated in Equation (3) (Malczewski, 1999b). In this study, the number of criteria is 9, so the RI is 1.45, according to the Randomness Index in Table 5. The consistency ratio was calculated as 0.05, which is smaller than the 0.10



limit value suggested by Saaty (1980), so the pairwise comparison judgments are consistent (Table 6):

$$CI = \frac{\lambda - n}{n - 1} \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

Table 5. Randomness Index (Malczewski, 1999b).

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Table 6. Calculation of consistency.

Step 1	Step 2
1x0.284+2x0.240+3x0.138+4x0.106+5x0.079+5x0.060	
+6x0.040+6x0.029+6x0.023=2.849	10.032
1/2x0.284+1x0.240+3x0.138+4x0.106+5x0.079+5x0.060	
+6x0.040+6x0.029+6x0.023=2.467	10.279
1/3x0.284+1/3x0.240+1x0.138+2x0.106+3x0.079+3x0.060	
+4x0.040+5x0.029+6x0.023=1.385	10.034
1/4x0.284+1/4x0.240+1/2x0.138+1x0.106+2x0.079+2x0.060	
+4x0.040+5x0.029+6x0.023=1.027	9.689



1/5x0.284+1/5x0.240+1/3x0.138+1/2x0.106+1x0.079+2x0.060 +3x0.040+4x0.029+5x0.023=0.754	9.542
1/5x0.284+1/5x0.240+1/3x0.138+1/2x0.106+1/2x0.079+1x0.060 +2x0.040+3x0.029+4x0.023=0.553	9.214
1/6x0.284+1/6x0.240+1/4x0.138+1/4x0.106+1/3x0.079+1/2x0.060 +1x0.040+2x0.029+3x0.023=0.372	9.292
1/6x0.284+1/6x0.240+1/5x0.138+1/5x0.106+1/4x0.079+1/3x0.060 +1/2x0.040+1x0.029+2x0.023=0.271	9.341
1/6x0.284+1/6x0.240+1/6x0.138+1/6x0.106+1/5x0.079+1/4x0.060 +1/3x0.040+1/2x0.029+1x0.023=0.210	9.114
$\lambda = 9.615$ $CI = 0.077$ $CR = 0.05$	

Preparation and normalization of criteria layers

Criterion layers were prepared, and the options in each criterion layer were rated in terms of flood hazard. Normalization procedures were then performed to standardize all criteria layers at the same value range.



Preparation of criteria layers

All criteria layers were prepared in the framework of Corum province borders. All of the criterion layers were prepared as raster data of 100 m pixel size considering the scale and resolution of the data used. The data and methods used in the preparation of the criteria layers are summarized in Table 7.

Table 7. Data and methods used in the preparation of criteria layers.

Criteria layers	Data	Method
Precipitation	The long-term average annual precipitation from meteorological stations data	The spatial distribution of precipitation was determined using Inverse Distance Weighted (IDW) method
Land use/cover	CORINE 2012	Current land use/cover was obtained by updating CORINE 2012 with visual interpretation of Landsat OLI data of 2018
Geology	1/100 000 scale and 1/500 000	The geological map was categorized into three classes:



	scale geological	new alluvium, old alluvium and
	maps	other
	таро	
Elevation	Aster GDEM	Aster GDEM data was converted to 100 m pixel size data, then sinks and peaks errors were eliminated from DEM using the "Fill Sinks" function in Arc Hydro, resulting in enhanced DEM data
Slope	Elevation	A slope layer was created using the enhanced DEM data
Aspect	Elevation	An aspect layer was created using the enhanced DEM data
Distance to rivers	Drainage network derived from Aster GDEM	Distance to rivers layer was created using the "Euclidean Distance" function of ArcGIS 10.0 software
Size of sub- basins	Aster GDEM	The sub-basins of the Kizilirmak and Yesilirmak basins in the study area were obtained using the drainage network and flow direction. For this purpose, the "Catchment Grid Delineation" function is used in Arc Hydro. Because this function produces the sub-



		basins in the grid form, sub- basin boundaries in grid form were converted into vector form and the area of each sub- basin was calculated
Shape of sub- basins	Aster GDEM	The length-to-width ratio of sub-basin was obtained by proportioning the distance in the direction of flow to distance perpendicular to this. According to this, the basins are categorized into three classes as circular, semicircular and elongated basin by using determined threshold values

Each criterion layer was evaluated in terms of flood hazard and scored at the sub-category level. For this purpose, land use/cover, geology, aspect, size of sub-basins, and shape of sub-basins were sub-categorized, and sub-categories were weighted by the method of pairwise comparison. From these layers, land use/cover, geology, aspect, and shape of sub-basins have class values with verbal terms, and since there are few sub-classes, pairwise comparisons have been made using these classes directly. However, since the total number of sub-basins is 27, it is



difficult to evaluate size of sub-basins by pairwise comparison. Therefore, pairwise comparisons have been made for grouped values.

The weights obtained by pairwise comparisons of sub-categories/grouped options for land use/cover, geology, aspect, size of sub-basins, and the shape of sub-basins and the consistency ratio of pairwise comparisons are summarized in Table 8. As the consistency ratio was below 0.10 for all criteria, all judgments were consistent.

Table 8. The coefficients of the sub-categories/grouped options of criteria obtained by pairwise comparisons and consistency ratios of pairwise comparisons.

Criteria	Sub-categories/Grouped options of	Weights	
	criteria		
Land	Water bodies	0.342	
use/cover	Wetlands	0.342	
(CD-0.08)	Artificial areas	0.216	
(<i>CR</i> =0.08)	Agricultural areas	0.073	
	Forest and semi-natural areas	0.029	
Geology	New alluvium	0.640	
(CR = 0.09)	Old alluvium		
(CK - 0.05)	Other	0.054	
Aspect	Flat	0.289	
(CR = 0.01)	North	0.197	
(CK - 0.01)	Northeast	0.123	
	Northwest	0.123	
	East	0.075	
	West	0.075	
	Southeast	0.045	



	Southwest	0.045
	South	0.028
Size of sub-	3 000-3 500	0.350
basins (km²)	2 500-3 000	0.237
(CR=0.02)	2 000-2 500	0.159
	1 500-2 000	0.106
	1 000-1 500	0.070
	500-1 000	0.046
	0-500	0.032
Shape of sub-		
basins	Circular	0.643
(CR = 0.06)		
	Semi-circular	0.283
	Elongated	0.074

The precipitation, elevation, slope, and distance to rivers were in the grid form, and each grid had different values. For this reason, instead of being grouped and scored by pairwise comparisons, the data were scaled in the range 0-1 using the "linear scale transformation". Here, 1 is most prone to flooding, and 0 is the least prone. Areas near to rivers are more affected by floods, and accumulation occurs where low slopes occur and low elevations are exposed to water from high elevations. For this purpose, it is assumed that there is a linear change between the border to rivers and the farthest places (1 for the border to rivers and 0 for the farthest places from rivers). Similarly, the elevation data (with the lowest elevation value of 1 and the highest elevation value of 0) and the slope data (with the lowest slope of 1 and the highest slope of 0) are scaled to



0-1. Precipitation data were also scaled between 0 and 1 (maximum precipitation value of 1 and minimum precipitation value of 0).

Normalization of criteria layers

Normalization has been performed so that all criteria layers are within the same evaluation range. The sum of all sub-categories/grouped options values obtained by pairwise comparisons for land use/cover, geology, aspect, size of sub-basins, and shape of sub-basins layers is 1. These data should be in the same scale range to be processed with precipitation, elevation, slope, and distance to rivers layers. For this purpose, "linear scale transformation" was applied to the layers in which options were scored by pairwise comparisons and the values were adjusted into the range 0-1. Because precipitation, elevation, slope, and distance to rivers were generated in the range 0-1 in the previous process step, this process is unnecessary for these. The normalized criteria layers are in the 0-1 interval, and the higher level of flood hazard is represented by values close to 1, while the lower level is represented by values close to 0.

Application of decision analysis with AHP



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Decision analysis was performed with AHP using criteria weights determined by pairwise comparison technique and normalized criteria layers, and a hazard map was created. This map was compared with Corum province flood inventory information, and the validity of the study was checked. Moreover, we examined the compatibility of the locations of existing and planned flood protection measures in Corum with the hazard map. The results of the analysis with AHP, the classification of the results, compatibility of the hazard map with flood inventory, and the examination of the existing and planned measures are discussed in detail in the Results and Discussion section.

Results and discussion

The value range of the AHP-generated hazard map was 0.38–0.92. Higher values indicate a greater level flood hazard. To provide a more interpretable visualization of the analysis results obtained by the AHP, an "equally interval classification" method was used in the ArcGIS 10.0 environment, and the flood hazard was classified into five groups: "1: Very high"; "2: High"; "3: Medium"; "4: Low", and "5: Very low" (Figure 3). The classification results suggest that 3 % of the Corum area (385 km²) exhibited very high level flood hazard; 25 % (3 205 km²) showed



high level flood hazard; 49 % (6 282 km 2) medium; 21 % (2 692 km 2) low, and 2 % (256 km 2) very low.

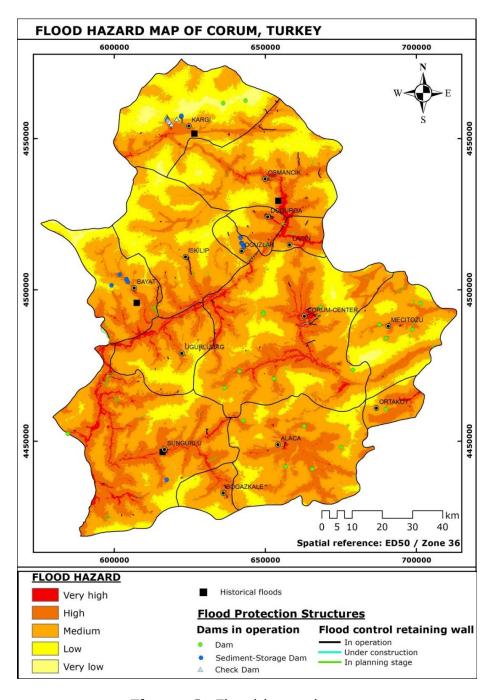


Figure 3. Flood hazard map.



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To test the accuracy of the flood hazard assessment obtained by AHP, the results of the analysis were compared with the flood inventory in Corum, and it was determined that the existing inventory and the hazard map are compatible (Figure 3). However, the main problem in this comparison was that only a limited number of historical floods had coordinated data. For this reason, the flood hazard map was also overlapped with the district boundaries of Corum, and the areal distribution of areas where flood hazard is important (flood hazard category is very high and high) for districts was obtained. As a result of this process, the higher values were in Sungurlu, Corum-Center, and Osmancik, respectively, and this situation was in line with Corum flood reports. Therefore, as a result of these comparisons, it is thought that the results of the analysis obtained will provide a realistic representation of the flood hazard areas.

To determine the land use/cover status of the very high and high level flood hazard areas, which can be considered as the most vulnerable zones in possible floods, the hazard maps and the land use/cover have been overlapped and the spatial usage information of the areas with very high and high level flood hazard have been obtained. According to this, it has been determined that about 43.64 km² of the artificial area has a very high level flood hazard, and 87.61 km² of the artificial area has a high level flood hazard in Corum (Table 9).

Table 9. Spatial use of very high and high flood hazard areas in Corum (km²).



	Artificial areas	Agricultural areas	Forest and semi-natural areas
Very high hazard	43.64	283.82	11.57
High hazard	87.61	2 418.93	717.42

A large number of flood protection structures have been built due to the experienced and possible floods in Corum. There are a total of 14 sediment-storage dams and 17 check dams. The total number of dams and small dams in operation is six and 15, respectively. A total of 206 projects for flood control retaining wall, erosion and sediment control structures have been carried out, of which 85 are in operation, 1 is under construction, and 120 are in the planning stage. The locations of the sediment-storage dams, flood control retaining wall, check dams, dams, and small dams overlapped with the hazard map are shown in Figure 3.

From Figure 3, it is seen that flood protection structures have been constructed or planned in many locations with very high level flood hazard in the existing hazard map. This proves that the hazard map presents problematic areas accurately. In this respect, in places where there is a very high and high flood hazard and flood protection measures have not been taken, it is necessary to prepare hazard maps based on hydraulic-hydrological modeling and accordingly to create flood protection projects must be made and these projects must be passed on to life as soon as possible. These measures are costly, need to be constructed primarily to start from settlements, areas with very high and high levels of hazard must be closely monitored, and measures must be completed in a timely



manner. Along with this, the establishment of new settlements and zoning studies should be carried out with care in hazardous locations where no precautions are taken.

Based on our findings, MCDA and GIS integration can be used effectively in determining the flood hazard. The weights of criteria and sub-categories/grouped options were determined by pairwise comparison technique in accordance with the AHP method. MCDA is subjective and introduces a risk of bias. To reduce this potential bias, the consistency ratio of the pairwise comparisons was calculated, and it was checked that the consistency ratios were below the 0.10 threshold value suggested by Saaty (1980).

The findings of this study were compared with the previous studies in Corum, and good agreement was obtained. Erdede and Öztürk (2016) stated that flood hazard is higher around the Strahler 7th-order stream segments in the Kizilirmak Basin. In our study, this region has been identified as having a very high flood hazard. In addition, it has been observed that the areas where flood hazard is important (very high and high level flood hazard areas) in Corum-Center are compatible with the areas indicated in Kaya and Akdemir (2019).

Conclusion



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Here we evaluated the flood hazard of Corum province, and a flood hazard map was prepared. In the preparation of the flood hazard map, AHP, which is a MCDA method, was used, and the analysis was carried out by weighting the factors affecting floods. By this approach, it was determined that 3 % of Corum has a very high level flood hazard, and 25 % has a high level flood hazard. The hazard map produced here is compatible with historical floods, suggesting that the hazard map provides a realistic representation of the areas that are likely to be affected by possible future floods.

When the structural measures were compared to the flood hazard map in Corum province, a large part of the existing measures corresponds to the very high and high flood hazard areas. Therefore, it is important to carry out detailed investigations and take necessary measures for other areas where flood hazard is important.

Based on our findings, we propose that the hazard assessment based on the MCDA provides a realistic view, correctly handles the factors affecting flood, and can be useful to determine locations where a hazard assessment based on hydraulic-hydrological models (requires high-resolution and large-scale data and is time-consuming and costly, and therefore not applicable to every field) is required. In this context, we recommend that flood hazard assessment studies should be carried out primarily by MCDA on the general scale, and then by hydraulic-hydrological models based on the areas prioritized by the MCDA.

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