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Flood Risk Analysis with AHP and the Role of Forests in Natural Flood Management: A Case Study from the North of Türkiye

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Abstract

Aim of studty: The aim of this study is to determine the flood risk map of the study area where floods and flood events are frequently encountered by AHP method.

Study area: The study was carried out within the boundaries of the Sinop Regional Directorate of Forestry, Ayancık Forest Management Directorate.

Material and method: The flood risk map of the study area was produced by Analytical Hierarchy Process (AHP) method. For AHP, 6 different criteria were used: slope, precipitations, aspect, stream distance, land use, and soil. Forest type maps of the study area were used to analyze the impact of forests on flood risk. In terms of forest structure, the stand structure was divided into 3 classes as coniferous, broadleaf, and mixed forest.

Main results: The results showed that flood risk varies with forest structure. Coniferous forest class was determined as the class with the lowest flood risk and mixed forest as the class with the highest flood risk.

Research highlights: It was determined that the flood risk changed according to the forest structure. Coniferous forest class was determined as the class with the least flood risk, and mixed forest was determined as the class with the highest flood risk.

Keywords: Flood Risk, AHP, Stand Structure, Forest Type, GIS

AHP ile Taşkın Risk Analizi ve Doğal Taşkın Yönetiminde Ormanların Rolü: Türkiye'nin Kuzeyinden Bir Vaka Çalışması

Öz

Çalışmanın amacı: Bu çalışmanın amacı, taşkın ve taşkın olaylarına sıkça rastlanan çalışma alanının taşkın risk haritasını AHP yöntemi ile belirlemektir.

Çalışma alanı: The study was carried out within the boundaries of the Sinop Regional Directorate of Forestry, Ayancık Forest Management Directorate.

Materyal ve yöntem: Çalışma alanı taşkın risk haritası Analitik Hiyerarşi Süreci (AHP) yöntemi ile üretildi. AHP için slope, precipitations, aspect, stream distance, land use and soil olmak üzere 6 farklı kriter kullanıldı. Ormanların taşkın riski üzerine etkisini analiz etmek için çalışma alanına ait forest type maps kullanıldı. Orman yapısı itibarı ile stand structure, coniferous, broadleaf and mixed forest olmak üzere 3 sınıfa ayrıldı.

Sonuçlar: Orman yapısına göre taşkın riskinin değiştiği tespit edildi. Coniferous forest sınıfı taşkın riski'nin en az olduğu, mixed forest ise taşkın riskinin fazla olduğu sınıf olarak tespit edildi.

Araştırma vurguları: Orman yapısının taşkın hasarının boyutunu farklı oranlarda azaltma eğiliminde olduğunu ve dolayısıyla taşkın olayları sırasında meydana gelecek zararları azaltma ve engelleme yeteneğine sahip olduğunu gösterdi.

Anahtar Kelimeler: Taşkın Riski, AHP, Stant Yapısı, Orman Tipi, CBS

Introduction

Climate change is the most important of the dangers threatening the world and humanity. Events such as global changes, extreme temperatures, droughts, and floods threaten all living things on Earth (Zeyno, 2022). Forests are one of the most important terrestrial ecosystems contributing to slowing and halting global climate change (Aksoy & Kaptan, 2022). Floods, which have recently increased with the effect of global climate change, cause significant damage to human life and livelihoods (Bhattacharjee & Behera, 2018). In the prevention of flood damage, hard structures such as embankments, river defenses, and dams are often used (Rasid & Paul, 1987; Shrubsole, 2000; Balica et al., 2015). However, studies have shown that hard structures are inadequate to prevent flood damage and tend to significantly alter the natural adaptive capacity of hazard-prone areas (Bhattacharjee & Behera, 2018). For this reason, it has been observed in recent years that ecosystem-based measures have been investigated in the control of flood risks (Gracia et al., 2018). Especially forests, which have taken on the role of slowing global climate change, are one of the natural ecosystems used to control floods and flood damages (Bhattacharjee & Behera, 2017).

Many studies on the resilience of forests to natural disasters include ecological resilience aspects of forests (Brand, 2009; Elmqvist et al., 2013; Unay-Gailhard et al., 2020). Due to the frequent forest fires in Mediterranean countries in recent years, researchers have investigated and provided information on the resilience of forests against fire disaster (Unay-Gailhard et al., 2020). The hydrological impact of forests has been studied for many years (Bosch & Hewlett, 1982; Bruijnzeel, 2004; Cıfor, 2005; Brookhuis & Hein, 2016). However, there are few studies investigating the role of forests on floods and floods. With the effect of global climate change, floods, and disasters are frequently encountered in the world and our country and cause a lot of material damage. To be less costly, the measures have been forced to focus on natural ecosystems (Wahren et al., 2012). Hydrological services provided by forest ecosystems (water supply, mitigation of water damage, water-related supporting services) are among the most important benefits to humanity (Brauman et al., 2007; Carvalho-Santos et al., 2014). Forests play an important role in slowing down flooding and flooding as they promote water infiltration, increase soil moisture content and allow water to be released gradually (Bruijnzeel, 2004). Again, the trunk, branch, and root structures of forest trees reduce surface runoff and maintain soil stability (Ilstedt et al., 2007; Lele, 2009; Carvalho-Santos et al., 2014). Another benefit of forests on floods is that they can reduce the annual water yield by evaporation and transpiration. All this shows that forests can contribute positively to water-related disasters such as floods and landslides (Calder & Aylward, 2006; Bredemeier, 2011). It can be said that forests can be a natural ecosystem to prevent floods and flood damage, but it is not a sufficient condition alone. Geology, soil structure, land conditions, precipitation, and socio-economic activities are effective in floods (Pregnolato et al., 2017; Bhattacharjee & Behera, 2018).

The fact that many parameters are effective on floods and flooding makes it necessary to use multi-criteria decision-making techniques in the analysis of these disasters. Many methods are used in the creation of flood and flood risk maps. Many researchers have also used data mining methods such as probabilistic models, decision trees, artificial neural networks, and fuzzy logic (Lee & Min, 2001; Clerici et al, 2006; Akgun & Türk, 2010). In recent years, developments in Geographic Information Systems (GIS) and Remote Sensing (RS) technologies have focused researchers in this direction (Zeyno, 2022). Many modeling techniques are performed using integrated techniques of remote sensing and geographic information systems (Ürker et al., 2023). Esin et al., (2022) using GIS and Analytical Hierarchy Process (AHP), created a flood risk map by using precipitation, slope, aspect, distance to rivers, geology, land use, and soil criteria. Desalegn and Mulu (2021), in Ethiopia, analyzed flood risk using AHP with GIS and HECRAS. Swain et al., (2020) created a flood risk map for Bihar, India, utilizing GIS and AHP. Rincón et al., (2018) in the Don River basin in the Greater Toronto Area, created a floodplain map using GIS and AHP. Shafapour Tehrany et al. (2017) In a study, they created a flood risk map using frequency ratio (FR), logistic regression (LR), and weight of evidence (WoE) methods.

In this study, it was aimed to determine the flood risk map of the study area, where flood and flood events are frequently encountered, by the AHP method. A total of 6 criteria, namely slope, precipitations, aspect, stream distance, land use, and soil, were used for the production of the flood risk map. To analyze the effects of forest areas on flood risk, stand structure data from forest cover type maps were used as input. Thus, it was tried to determine the ways of realizing the decisions and policies to be taken for the planning and management of forest ecosystems by the flood risk and management at the same time. The study aimed to provide forest planners with detailed information on which stand type should be used and planned in areas with high flood risk. The study includes two sub-questions in particular: "Can the flood risk map of the study area be produced by the AHP method using the criteria effective on flooding and flooding identified from the literature? If so, do forest stand structures have different effects on flood and flood risk?".

Material and Methods

Study Area

The study was carried out within the boundaries of the Sinop Regional Directorate of Forestry, Ayancık Forest Management Directorate. The study boundary is located between 41° 39′ 30″- 40° 45′ 30″ North latitude and 34° 37′ 26″- 34° 43′ 06″ East longitude. Ayancık Forest Management Directorate consists of a total of 12 units, 11 Forest planning units, and 1 Warehouse unit. Ayancık Forest Management Directorate consists of 77% forested area and 23% non-forest area. Of the forested area, 88% is productive forest and 12% is closed forest with gaps (Anonymus, 2011). The geographical location of the study area is shown in Figure 1. The study area was subjected to a major flood disaster on 11.08.2021 (Figure 2). The flood disaster that occurred in the Ayancık district of Sinop province was caused by the overflow of the Ayancık Stream. Ayancık Stream has a catchment area of approximately 670 km^2 and flows directly into the Black Sea from the Ayancık coast. Ayancık district, which is one of the settlements where the flood disaster is most intensely experienced, is located at the outlet point of the basin. For this reason, the settlements within the borders of the district were exposed to the maximum flow occurring on the basin surface. (AFAD, 2021). Again, since the study area covers the most productive forest areas of our country, this region was chosen to examine the role of forests on floods.

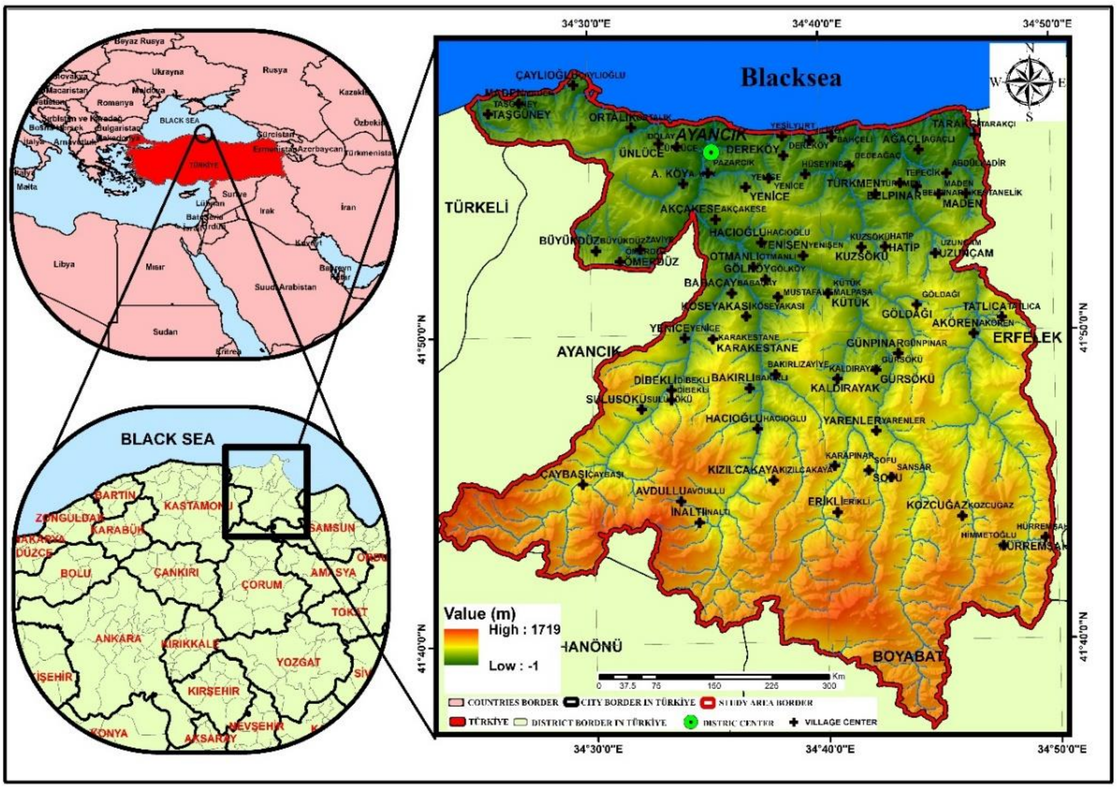

Figure 1. Location map of the study area

Figure 2. Flood damage images

Data

In the study, 6 criteria were used in the creation of the flood risk map. These are; slope, precipitations, aspect, stream distance, land use, and soil. A digital elevation model (DEM) was used to create slope and aspect maps of the study area. DEM was obtained from the ALOS-PALSAR satellite image. The stream distance map was obtained by using vector data obtained from the open street map and DEM. The land use map was created in the ArcGIS environment using Corine data from the National Land Cover Classification System (TOB, 2022) of the Ministry of Agriculture and Forestry. Soil data for the study area were obtained from the official website of the General Directorate of Mineral Research and Exploration (MRE) (MRE, 2021). Finally, the forest cover type map of the study area was used to analyze the impact of forests on flood risk (Figure 3).

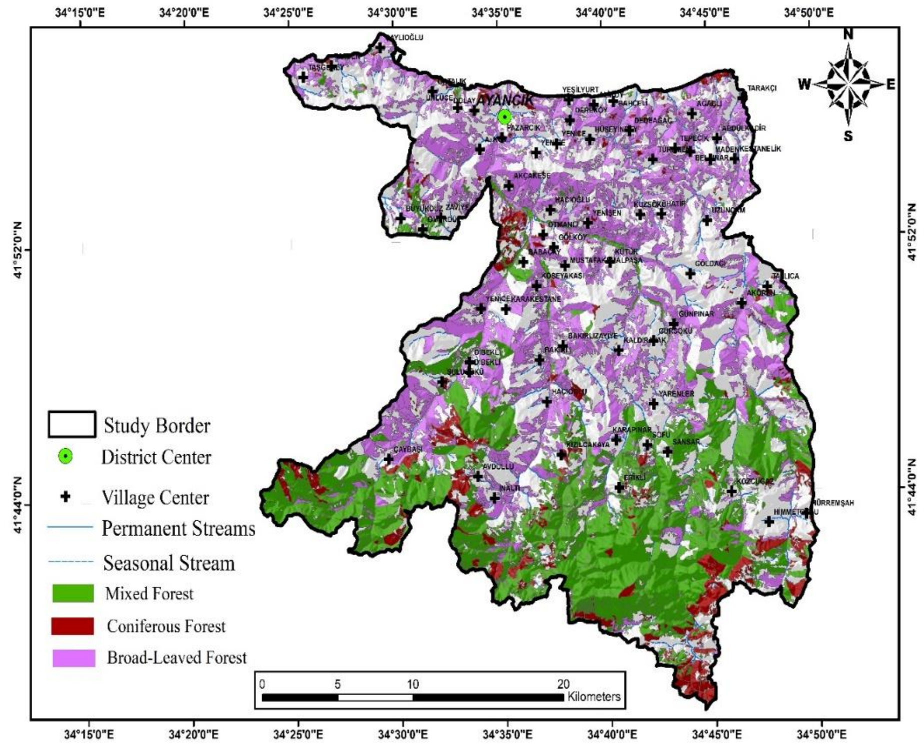

Figure 3. Forest type map of the study area

Method

The study was carried out in two stages. In the first stage, the flood risk map of the study area was obtained using the Analytical Hierarchy Process (AHP) multi-criteria decision-making method. In the second stage, the effect of forests on flood risk was analyzed using the forest type map of the study area. The general workflow diagram of the study is shown in Figure 4.

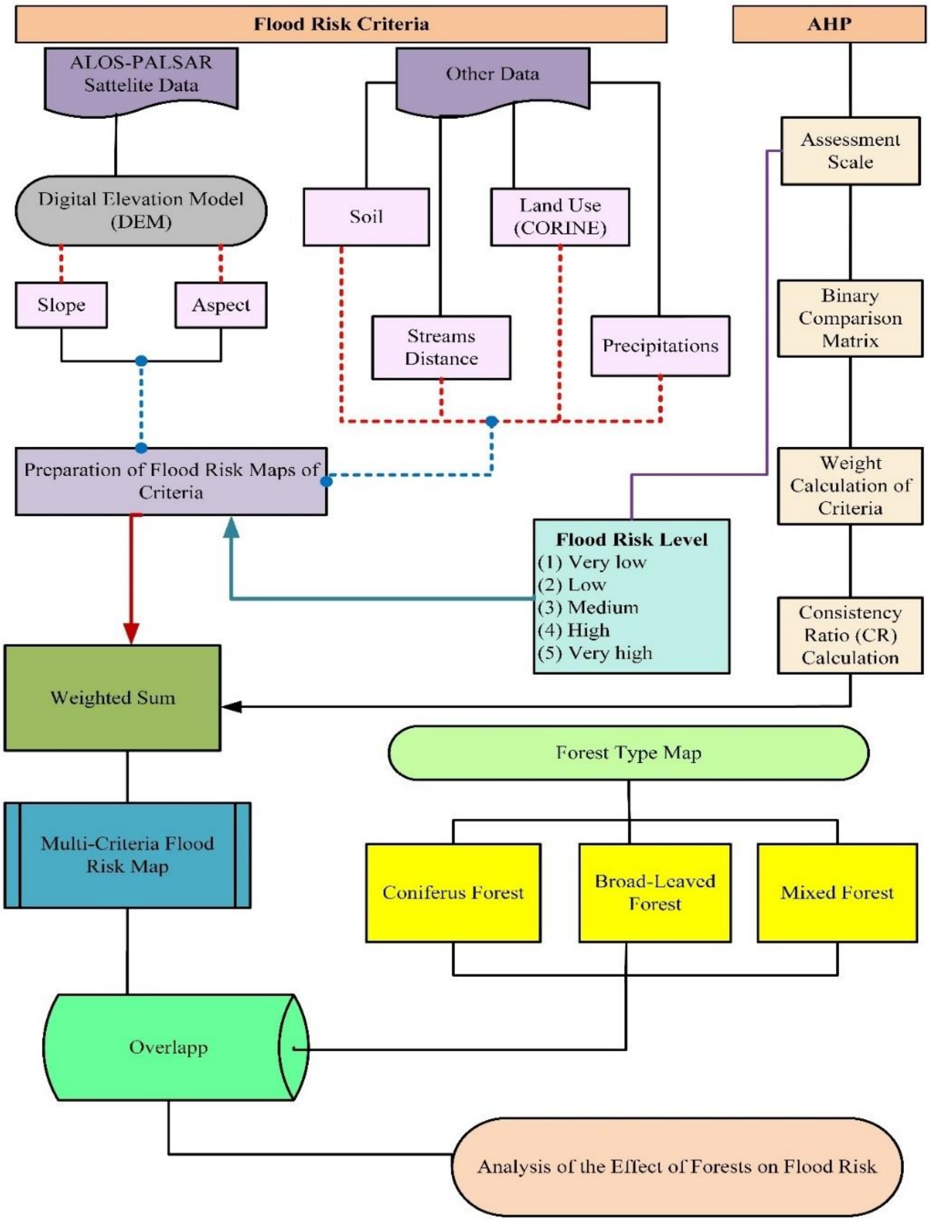

Figure 4. Workflow diagram for the study

Analytical hierarchy process and landslide susceptibility analysis

Analytical Hierarchy Process (AHP), one of the multi-criteria decision-making methods, was used to create the flood risk map of the study area using 6 criteria. These criteria are; slope, precipitations, aspect, stream distance, land use, and soil. Flood risk analysis with AHP analysis was carried out in 4 main stages. In the first stage, the AHP evaluation scale was determined to adjust the level of importance between the criteria. The scale shown in Table 1 was used in the study (Saaty, 2012; Sivrikaya et al., 2022).

Table 1. The pairwise comparison scale in the AHP

Importance scale	Definitions of importance	Explanation
1	Equal	Two activities contribute equally to the goal
3	Moderate	Experience and judgment are slightly preferable to another
5	Strong	Experience and judgment are strongly preferable to another
7	Very Strong	Experience and judgment are very strongly preferable to another
9	Extreme	Experience and judgment are of the highest possible order of affirmation
2, 4, 6, 8	Intermediate	When you need to make a compromise

In the second stage, a pairwise comparison matrix for each criterion was created using the Table 1 scale. The importance levels of the classes for each criterion were determined. For the Slope criterion, 5 classes were determined as % (0-7, 7.1-15, 16-20, 21-30, and >31). The class with the highest slope rating was scaled to be the riskiest class and the most important score rating. The aspect map was also produced in ArcGIS software using DEM data. For Aspect, 3 classes were determined as North, South, and East-West, and North was determined as the class with the most important score in this criterion. The land use criterion was divided into 5 classes: agriculture, settlement, pasture, forest, and water bodies. In the classes, agriculture and settlement classes were evaluated and scaled as areas with higher flood risk. Stream distance criterion was divided into 5 classes (250 m, 500 m, 750 m, 1000 m, 1250 m). The stream map of the study area was obtained using DEM and ArcGIS software hydrology tools. It was then intersected with the streams data obtained from OSM and made ready for analysis. After the stream vectors were created, a stream distance map was obtained with a buffer zoon. The zones close to the streams were scored as the most risky areas. DEM and ArcGIS software was used for the precipitation map of the study area. First, fixed meteorological station data were obtained. Then, the number of stations was increased by randomly assigning points to the study area. Based on the elevation in the fixed station data, the total precipitation amount of each station was calculated by the Schreiber formula (Eq.1) in each 100 m elevation interval as 54 mm down or up ± according to the elevation range. Finally, using precipitation data for each point, a general precipitation map of the study area was created with the IDW tool. Precipitations criterion was divided into 5 classes (1321-1534 mm, 1183-1320 mm, 1026-1182 mm, 867.3-1025 mm, and 679.5 - 867.2 mm). Classes with more rainfall were scored as the riskiest.

$$Ph = P0 + (54 \times h) \quad (1)$$

In the formula, Ph is the precipitation (mm) of a point of known elevation, and h is the elevation difference (hectometer) between Ph and $P0$. $P0$ is the precipitation value and the precipitation amount (mm) of the comparison station with known elevation. Finally, a soil map of the study area was created. Soil data were obtained from the General Directorate of Mineral Research and Exploration (MRE) and digitized by cutting the map according to the study area. The digitized soil map was divided into 5 classes rivers and floodplains, alluvial soils, colluvial soils, forest soil, and gray-brown podzolic soils. Rivers and floodplains, and alluvial soil classes were scaled to the highest flood risk. After the importance scoring for the criteria was completed, the third stage of the AHP analysis, the weight calculations for the criteria, was performed. In the final stage of the AHP analysis, the consistency ratio (CR) was calculated to measure the consistency of the randomly generated importance matrix between the criteria (Eq. 2). The consistency ratio was calculated as the ratio of the consistency index value (CI) to the random index value (RI). The RI value is a constant coefficient depending on the number of criteria, while the CI value was calculated as the sum of the consistency mean and the number of criteria (Eq. 3).

$$CR = \frac{CI}{RI} \quad (2)$$

$$CI = \frac{\lambda - n}{n - 1} \qquad (3)$$

**λ tutarlılık vektör ortalaması toplamı, n kriter sayısı, CI tutarlılık indeks, CR tutarlılık oranı

It is recommended that the consistency ratio for AHP analysis should not exceed 10%. If this ratio exceeds 10%, it means that there is an inconsistency in the evaluation scale between the criteria and should be re-evaluated (Saaty, 2012). After the weight calculations for the criteria were obtained in the AHP process, flood risk maps of each criterion were created. Finally, using the weight values of each criterion, the flood risk map of the study area was obtained using the "weight sum" command in ArcGIS software.

Impact of forests on flood risk

The forest type map of the study area was used to measure the effect of forests on flood risk through the flood risk map of the study area. Stand structure was divided into 3 classes as coniferous forest, broadleaf forest, and mixed forest. Then, the vector data for these 3 classes were overlaid separately with the flood risk map of the study area, and the flood risk values of each class were calculated and interpreted.

Result

AHP Flood Risk Analysis

In the AHP process, class weights for the criteria used in the analysis were determined to produce an overall flood risk map of the study area. Then, the consistency ratio (CR) was calculated to measure the consistency of the randomly generated importance matrix between the criteria. The weight and CR results for the criteria are shown in Table 2 and the maps for the criteria are shown in Figure 5. When the results are analyzed, the highest weight for the land use criterion was calculated for the agriculture class (0.503). The lowest was calculated for the water bodies class (0.035).

Table 2. Weights and consistency ratios of all criteria and classes according to the AHP model

Layers															
Stream distance	1	2	3	4	5	Weight	CR	Slope (%)	1	2	3	4	5	Weight	CR
250 m	1	3	5	7	9	0.503	0.08	31>	1	3	5	7	9	0.503	0.08
500 m		1	3	5	7	0.26		21 - 30		1	3	5	7	0.26	
750 m			1	3	5	0.134		16 - 20			1	3	5	0.134	
1000 m				1	3	0.068		7.01.2015				1	3	0.068	
1250 m					1	0.035		0 - 7					1	0.035	
Land use (Corine)								Soil groups							
Agriculture	1	3	5	7	9	0.503	0.08	Rivers and Floodplains	1	2	3	4	5	0.413	0.04
Settlement		1	3	5	7	0.26		Alluvial Soils		1	2	3	4	0.259	
Pasture			1	3	5	0.134		Colluvial Soils			1	2	3	0.159	
Forest				1	3	0.068		Forest Soil				1	3	0.11	
Water bodies					1	0.035		Gray Brown Podzolic Soils					1	0.058	
Layers															
Aspect	1	2	3	4	5	Weight	CR	Precipitations (mm/yıl)	1	2	3	4	5	Weight	CR
North	1	2	3			0.633	0.05	1321 - 1534 mm	1	3	5	7	9	0.503	0.08
South		1	2			0.26		1183 - 1320 mm		1	3	5	7	0.26	
East-West			1			0.106		1026 - 1182 mm			1	3	5	0.134	
								867,3 - 1025 mm				1	3	0.068	
								679.5 - 867.2 mm					1	0.035	

In the slope degrees, the highest weight was calculated for the 31>% class (0.503). In the Streams distance criterion, the highest weight was calculated for the class at a distance of 250 m (0.503). In the Soil criterion, the highest weight was calculated for the rivers and floodplains class (0.413). The lowest weight was calculated for the grey-brown podzolic soils class (0.058). Within the Precipitation criterion, the highest weight value was calculated for the highest precipitation class (1321 - 1534 mm) (0.503).

The lowest was calculated for the 679.5 - 867.2 mm class (0.035). In the Aspect criterion, the North class was 0.633, the South class was 0.260, and finally, the East-West class was 0.106. It is recommended that the consistency ratio (CR) for AHP analysis should not exceed 10%. If this ratio exceeds 10%, it means that there is an inconsistency in the evaluation scale between the criteria and should be re-evaluated (Saaty, 2012). In the study, it is seen that the CR ratio for all criteria is below 10% (Table 2). These results show that the evaluation scale of each criterion between the classes is made consistently.

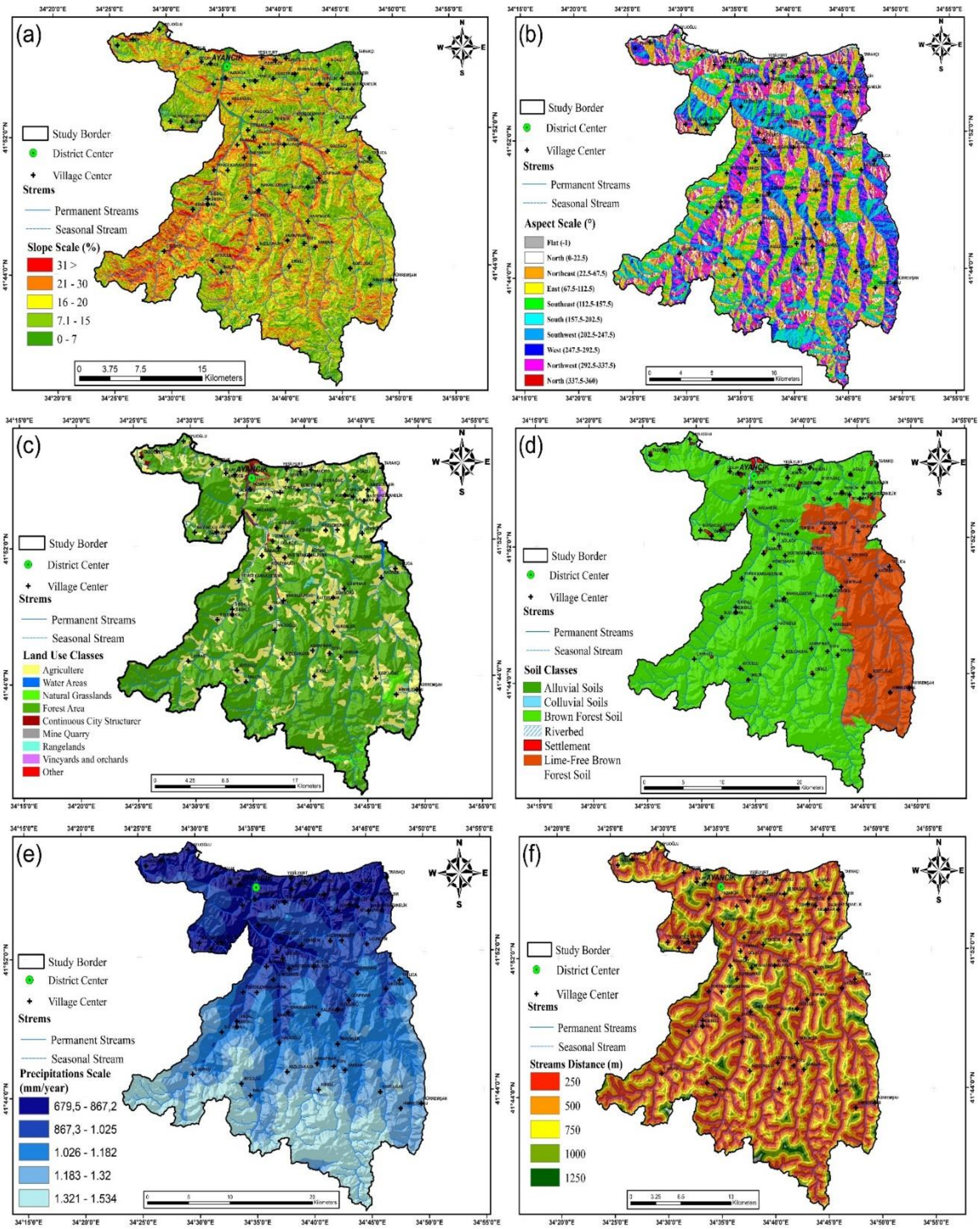

Figure 5. Spatial distribution of flood conditioning factors; (a) Slope in percent, (b) Aspect in degree, (c) Land use/land cover characteristics, (d) Soil texture, (e) Annual precipitation, and (f) Distance from active streams

After the weighted sensitivity map for the criteria was created, the evaluation scale, weights, and consistency ratio (CR) of the 6 criteria used in the analysis were calculated to create the general flood risk map of the study area (Table 3).

Table 3. Evaluation scale, weights, and consistency ratios of all criteria according to the AHP model

Criteria	Flood Risk Analaysis							
	1	2	3	4	5	6	Weights	CR
(1) Slope	1	2	4	5	7	9	0.401	0.08
(2) Soil		1	3	4	5	9	0.272	
(3) Precipitations			1	3	4	7	0.156	
(4) Stream distance				1	3	5	0.094	
(5) Land use					1	3	0.051	
(6) Aspect						1	0.026	

When Table 3 is analyzed, the criteria were ranked in terms of importance on flood risk. The most important criterion with the highest weight was determined as slope. According to the comparison matrix created by the AHP method, parameter weights were calculated as 0.401 for slope, 0.272 for soil, 0.156 for precipitations, 0.094 for stream distance, 0.051 for land use, and finally 0.026 for aspect. The flood risk map of the study area is shown in Figure 6. The consistency ratio (CR) in the study area flood risk comparison matrix was below 10%. This shows that the evaluation scale of the criteria used for flood risk is consistent and usable. The flood risk map was produced using the "Weighted Sum" tool in ArcGIS software. The flood risk map of the study area was divided into 5 classes by general classification. These classes were grouped as "very low", "low", "medium", "high" and "very high". Spatial and proportional values for the susceptibility classes are shown in Table 4.

Table 4. Area values for flood risk levels

Value Range	Flood Risk Level	Area (ha)	%
0.053 - 0.13	Very Low	19696.73	24.83
0.14 - 0.16	Low	25885.28	32.64
0.17 - 0.18	Medium	21719.52	27.38
0.19 - 0.22	High	9107.97	11.48
0.23 - 0.40	Very High	2907.42	3.67

When the flood risk results of the study area are analyzed, it is seen that 24.83% (19696.73 ha) of the area has very low flood risk. The lowest class in terms of area and proportion is a very high class (3.8% - 2907.42 ha). The highest class in terms of area and proportion is low (32.64% - 25885.28 ha). After the low class, the class with the highest is medium (27.38% - 21719.52 ha). Finally, the high class was the fourth in the flood risk spatial ranking (11.48% - 9107.97 ha). When evaluated spatially, it was determined that the general study area was in low and medium flood risk. The general study area was found to be at medium and high risk in terms of flood.

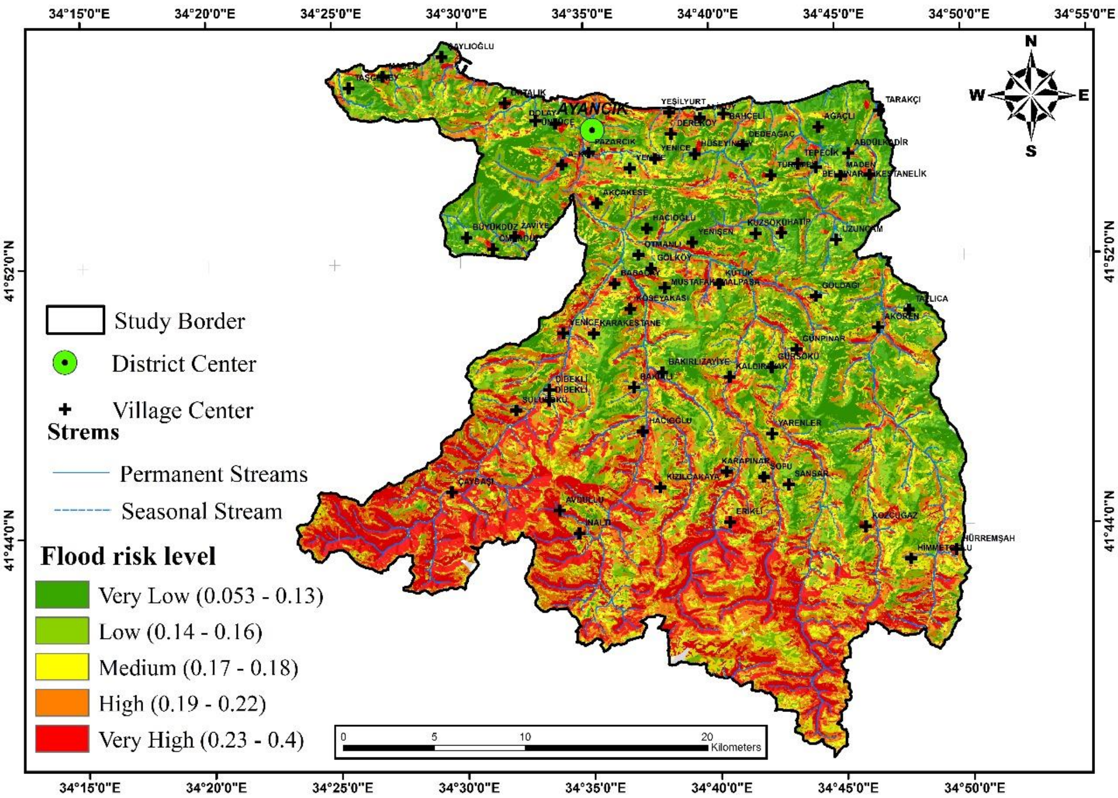

Figure 6. Flood risk map of the study area

Impact results of forests on flood risk

In the study, the results were analyzed by overlapping the flood risk map produced by AHP with the forest type map of the study area. The forest map was divided into 3 classes as coniferous, broadleaf, and mixed forest for stand structure. Flood risk levels were determined by overlapping the areas related to each class with the flood risk map. Descriptive statistics and area values for flood risk values for the stand structure are shown in Table 5.

Table 5. Descriptive statistics of flood risk for forest criteria

Classes	Area(ha)	Area (%)	Min.	Max.	Mean	Std.
Coniferous Forest	72224.1	33.29	0.058	0.377	0.168	0.030
Broadleaf Forest	99848.4	46.02	0.053	0.389	0.181	0.042
Mixed Forest	44876.6	20.68	0.063	0.401	0.189	0.035

When Table 5 is analyzed, it is seen that the highest area belongs to the broad-leaved class in the stand structure criterion (46.02%). Then, the highest area values belong to coniferous (33.29%) and mixed (20.68%) classes, respectively. The minimum, maximum, and mean flood risk values of the coniferous class were calculated as 0.058, 0.377, and 0.168, respectively. The minimum, maximum, and mean flood risk values of the broadleaf class were calculated as 0.053, 0.389, and 0.181, respectively. Finally, the minimum, maximum, and mean flood risk values for the mixed class were calculated as 0.063, 0.401, and 0.189, respectively. Flood risk maps for the stand structure classes are shown in Figure 7.

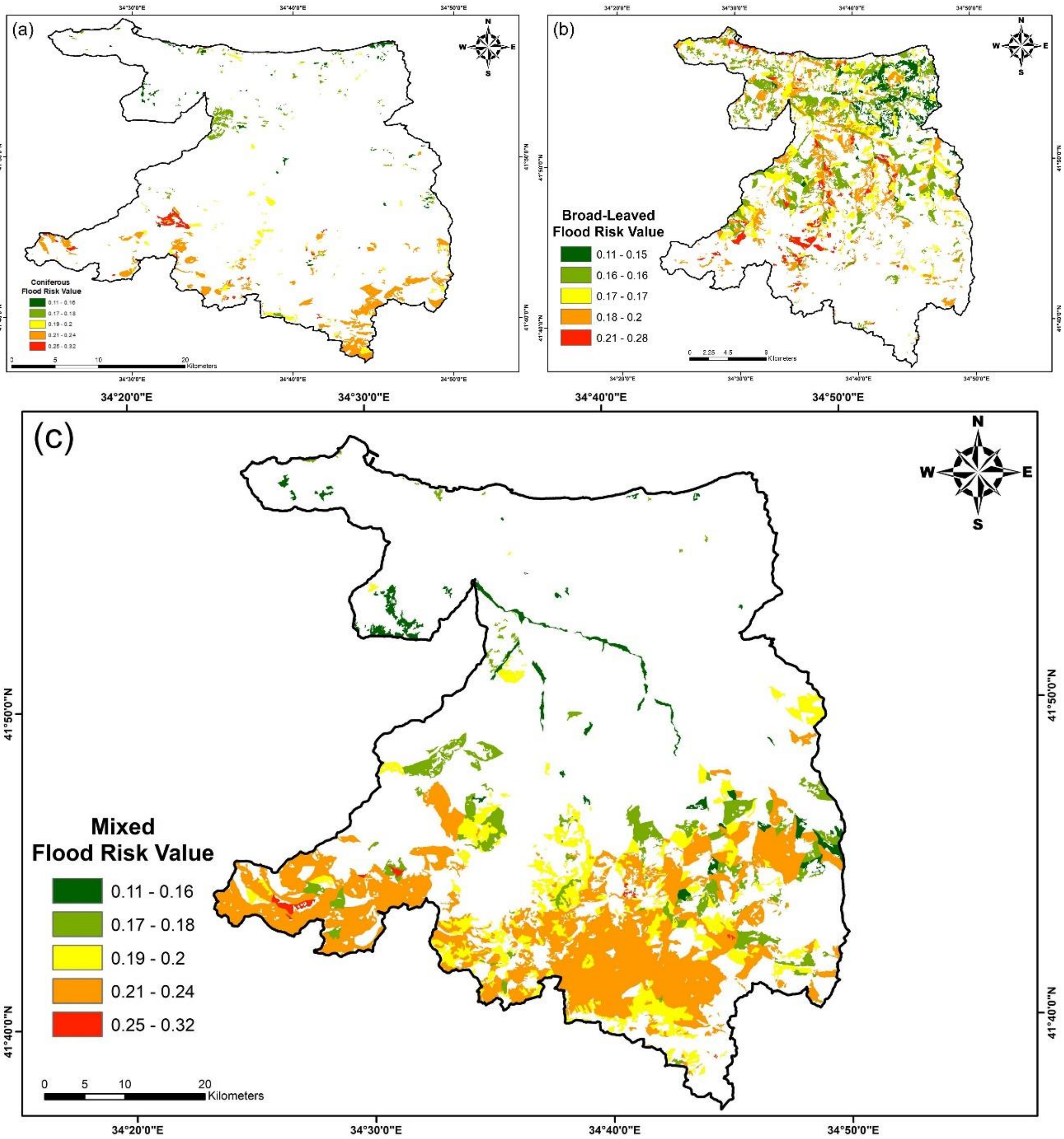

Figure 7. Flood risk map of the forest area

Discussion

The study was carried out in two main stages. In the first stage, a flood risk map of the study area was created using a total of 6 criteria (slope, precipitations, aspect, stream distance, land use, and soil). The AHP method was used in the creation of the flood risk map. In the second stage, the effects of forests on flood risk were analyzed. There are very few studies that specifically and systematically analyze the effects of forests on flood risk. In this study, flood risk effects of forest areas in terms of stand structure (coniferous, broad-leaved, and mixed) were analyzed.

The Flood Risk Analysis Using AHP

In the study, a flood risk map of the study area was produced with AHP to determine the flood risk areas. The criteria weights in the matrix created by the AHP method are; slope 0.401, soil 0.272, precipitations 0.156, stream distance 0.094, land use 0.051, and aspect 0.026. According to these results, the most effective criteria for flood risk in the study area were determined as slope, soil, and precipitations. There are many studies in which flood risk maps were created with AHP. In some flood risk analyses, various topographic features such as hydrology, geomorphology, and climatology were used as criteria. Information on the criteria (DEM) was collected using remote sensing methods and analyzed with GIS (Das & Pardeshi, 2018; Wang et al., 2019; Das, 2020; Shekar & Mathew, 2023). Oğuz et al., (2016) In the study conducted by A, according to the multi-criteria decision-making method at the Artvin province scale, the land use, slope, soil, geology, geology, aspect, distance to the river and maximum precipitation maps of the areas were graded according to the CCA method in GIS environment and the flood risk map was determined in GIS environment. According to the risk map obtained, it is stated that the areas with "very high" and "high" flood risk are located in the residential area and these areas are the places with the highest probability of being damaged in a possible flood, and the flood risk is higher in the parts of the study area close to the sea, where the slope is low, the rainfall is high and the agricultural areas are common, and that the inclusion of hydrological modeling in the study in future studies will lead to more accurate results. Stefanidis et al., (2013) conducted a flood risk analysis in northern Greece and found that anthropogenic factors are more effective than natural factors. Souissi et al., (2020) used 8 criteria: elevation, land use/land cover, lithology, rainfall intensity, drainage density, distance from the drainage network, slope, and groundwater depth in a flood risk assessment study. The results showed that the elevation criterion was the criterion with the highest weight in flood occurrence. Hammami et al., (2019) found that the land use criterion has the highest impact in their flood risk analysis for Tunisia. In research on flood risk assessment, we have seen that the most prominent flood disaster factor in a multi-criteria system in various regions is different. Therefore, measures against flood risk should be taken according to the results. Radwan et al., (2019) used the integration of GIS, remote sensing (RS), and AHP in a flood risk analysis. They used a digital elevation model with a precision of 30 m, spatial soil and geological maps, historical daily rainfall records, and data on stormwater drainage systems. They found that the greatest impact was in the precipitation criterion. Meral and Eroğlu, (2021) conducted flood risk analysis using the AHP method. They used a total of 7 criteria in the AHP process: slope, aspect, distance to the stream, land use, geology, soil, and precipitation. They determined that precipitation was the most effective criterion for flood risk.

Impact of Forests on Flood Risk

In this study, by combining forest type maps and flood risk data, the effects of the stand structure of forest areas on flood risk were analyzed. It was determined that different forest stands have different flood risk values. The average flood risk values of coniferous, broad-leaved, and mixed forest areas for the stand structure criterion were 0.181, 0.168, and 0.189, respectively (Table 5). The maximum flood risk values of coniferous, broad-leaved, and mixed forest areas were calculated as 0.377, 0.389, and 0.463, respectively. The results show that mixed forest form is the most susceptible to flood risk, while coniferous forests are the least susceptible. This is directly related to the root system. Because especially coniferous tree structures form a deeper root system compared to leafy tree species. Therefore, the coniferous class is less sensitive than the broad-leaved class. In a study, it was found that the amount of water collected in leaves, trunks, and branches and evaporated back to the atmosphere before reaching the ground was higher in coniferous forests than in broad-leaf and mixed forests (Llorens & Domingo, 2007; Carlyle-Moses & Gash, 2011; Cooper et al., 2021). This supports that coniferous forests are an effective forest form for flood risk reduction. Other studies also show that, in general, the presence of forest cover tends not only to reduce the frequency of flood occurrence but also to protect human life and property (Alongi, 2008; Das & Crépin, 2013; Adger et al., 2005; Tan-Soo et al., 2016; Brookhuis & Hein, 2016; Bhattacharjee & Behera, 2018). In addition to their ability to retain water, forests reduce the availability of material for transport as their root systems stabilize the soil and retain material on slopes (Sakals et al., 2006). In another study, it was found that forests increase soil infiltration and retention of water and delay the transition to surface runoff (Noguchi et al., 2001; Sebald et al., 2019). This is proof that coniferous forests with deep root systems have less flood risk. In another study, the effects of forests on flood risk in terms of crown closure were investigated. The results showed that the flood risk potential increased as the canopy decreased (Seidl et al., 2017). In this case, it is directly related to the leaf surface area in terms of ground cover. In our study, it supports that broadleaf forests are at a medium level in terms of flood risk status. In another study, it was determined that forests play an important role in preventing flood events (Kourgialas et al., 2011). Dixon et al., (2016) in a study they conducted, emphasized that floodplain forests in small drainage basins will make a great contribution to the reduction of flood risk. When the general study data are evaluated, it will help to take precautions for the risks that may occur, especially in our study area where flood risk and destruction are high.

Conclusions

A total of 6 criteria and the AHP method were used to determine the flood risk of the study area. Then, the effect of forests on flood risk was analyzed in terms of stand structure. In general, the coniferous class was found to be the most successful class in terms of reducing flood risk in the stand structure criterion. In forest management, optimizing stand structure according to flood risk distribution is important for the integrity of economic, social, and ecological benefits. In further studies, it is important to examine the flood risk in terms of tree species, and which tree species will be more beneficial to use in areas with high flood risk in new afforestation. In addition, our results proved the effectiveness of forests against flood risk. Promoting ecosystem-based methods, such as forest conservation and regeneration in flood-prone areas, can help prevent flood hazards due to climate change and the resulting damages caused by frequent flooding. Forest resources can repair and restore themselves. They can provide significant advantages over traditional structural flood prevention approaches. Forests play an important role in natural flood management by absorbing and slowing precipitation, reducing runoff and stabilising river banks. This can help reduce flood risk. In areas with flood and flood risk, especially in land uses with dense forest form similar to our study area, we believe that establishing the most beneficial structure in terms of forest types will provide a slowing and protective effect on disasters.

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N/A

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Author contributions

Conceptualization: H.A.; Investigation: H.A.; Material and Methodology: H.A.; Supervision: H.A.; Visualization: H.A.; Writing-Original Draft: H.A.; Writing-review & Editing: H.A.; Other: H.A. Author has read and agreed to the published version of manuscript.

Conflict of Interest

The author declare that he has no competing interests or conflicts of interest.

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