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STRUCTURAL FLOOD ANALYSIS BASED ON THE HYDRAULIC MODEL OF THE KÜÇÜK AKSU RIVER

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Anahtar Kelimeler
Flood risk analysis,
GIS,
Hec-RAS,
Structual flood analysis,
Küçük Aksu River.

Abstract
In this study, flood risk areas were determined with Hec-RAS hydraulic model for the Küçük Aksu River in Antalya, Turkey. Firstly, Hec-RAS models were developed according to different recurrence flow rates and, flood propagation maps and flood depth maps were generated. As a result of the model that was developed by using a 100-year flood recurrence flow rate, it was seen that 6.04 ha of the residential area and 33.73 ha of the agricultural area is submerged. The maximum water level was determined as 11.60 m according to the 100-year flood recurrence flow rate. Then, structural flood analysis was performed using the depth-damage graph for the Küçük Aksu River. As a result of this analysis, it was seen that the economic loss caused by floods was between 1.152 million-1.946 million TL.

KÜÇÜK AKSU ÇAYI'NDA HIDROLIK MODELE DAYALI YAPISAL TAŞKIN ANALİZİ

Keywords
Taşkın risk analizi,
CBS,
Hec-RAS,
Yapısal taşkın analizi,
Küçük Aksu Çayı.

Öz
Bu çalışmada, Antalya ilinde bulunan Küçük Aksu Çayı'nda Hec-RAS ile taşkın riski olan alanlar belirlenmiştir. İlk olarak, farklı tekerrür debilerine göre Hec-RAS modelleri geliştirilmiş ve taşkın yayılım haritaları ile taşkın derinlik haritaları oluşturulmuştur. 100 yıllık taşkın tekerrür debisi kullanılarak geliştirilen model sonucunda 6,04 ha yerleşim alanı ile 33,73 ha tarım alanının su altında kaldığı görülmüştür. 100 yıllık taşkın tekerrür debisine karşılık gelen maksimum su yüksekliği 11,60 m olarak saptanmıştır. Daha sonra derinlik-hasar grafiği yardımıyla Küçük Aksu Çayı için yapısal taşkın analizi yapılmıştır. Yapılan analiz sonucunda taşkınların neden olduğu ekonomik kaybın 1.152 milyon-1.946 milyon TL arasında olduğu görülmüştür.

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1. Introduction

As a stream overflows from its bed, floods occur and we can define floods as flows that can damage the settlements, agricultural lands, and living things around the stream (Kılıçer and Özgüler, 2002). Floods occur as a result of precipitation that exceeds the long-term average precipitation, snow melting and, rarely collapsing and overflowing of dams (Onuşluel and Harmancıoğlu, 2002).

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Floods are related to not only meteorological events but also the industrialization and the urbanization in developing countries. Also, the diversity and the intensity of human activity on river basins increase flood events significantly. For this reason, the hydrological balance of the basin deteriorates and as a result of this, a large amount of life and property losses occur. The land structure changes with the increase of settlements, newly constructed roads, and newly established facilities in the river basins and the lands are being used more intensively. Also, forests and pastures are destroyed with unsuitable agricultural practices. Because of all these reasons, flood disasters become more common (Özcan, 2008).

According to the data of the Disaster and Emergency Management Presidency (AFAD) (AFAD, 2019), a total of 378 flood events occurred in Turkey between 2009-2019. In these flood events, 75 people lost their lives, 98 people were injured, 276 buildings collapsed, and 22053 buildings were damaged. For this reason, the determination of flood risks and areas affected by floods in any basin will enable the search and rescue activities in a quicker and more effective way in a possible flood event. The hydraulic model is known as the most suitable method for determining flood risk areas. Therefore, there are many studies about hydraulic models used in flood risk analysis in the literature (Shrestha et al., 2020; Nigussie and Altunkaynak, 2019; Erana et al., 2018). Komolafe (2021) investigated use of integrated 2-dimensional distributed flood model and terrain-based HAND model to define flood characteristics in the Ichinomiya River basin in Japan. Gumbel distribution was used to determine the intensity-duration-frequency of precipitation from 1996 to 2014 in the study area. Mu et al. (2021) determined the flood water depth and flood areas with the Flo-2D model using four different precipitation data, namely R1 (highest at the fifth hour), R2 (highest at 20th hour), R3 (highest in the first hour) and R4 (highest at 13th hour), in the city of Hue in Vietnam. Choo et al. (2020) used the Spatial Runoff Assesement Tool (S-RAT, Spatial Flow Assessment Tool) and the Flood Inundation model (FLO-2D model) to calculate the flood level in urban areas. In addition, during the analysis, rainfall-flood depth curve and Flood-Vehicle Speed curve were given, and a traffic disruption map was prepared with it. They compared the results of the study with previous studies and confirmed with rainfall events in 2011. As a result of the comparisons, they said that this study will help the driver to choose a route by using urban flood damage analysis and vehicle driving speed analysis.

Khattak et al. (2016) created flood maps with the Hec-RAS model to help actions taking precautions against floods in the Kabul River in Pakistan. They extracted the geometric data of the stream from the digital elevation model. To determine the recurrence flow rate, they applied the log-normal (LN), Gumbel (G), and log-Pearson type 3 (LP3) distributions to the flow data and determined that LP3 is the most appropriate distribution with the Kolmogorov-Smirnov (K-S) test. When they compared the created flood maps with the images of the flood that occurred in 2010, they stated that there is a close consistency between the images and the maps. Taş et al. (2016) determined the flood flow rates calculated for different recurrence periods and the water levels and the areas to be inundated by using Hec-RAS in Akarçay Afyon Sub-Basin. Then, they estimated flood damage with the help of average water depth and depth-loss curves. As a result of the estimation, they saw that the flood losses varied between approximately 10 and 130 million TL depending on the increase in recurrence intervals. Shirzad (2017) made a flood analysis with recurrence rates of 25, 50, 100 years at the Maden Creek in the province of Kocaeli. With Hec-RAS, the areas under flood risk were determined by producing flood propagation maps of the stream before and after the reclamation. Sönmez and Demir (2017) performed flood risk analysis on Yeşilcay and Göksu streams located in the east and west of Ağva district with a one-dimensional hydraulic model. They prepared the flood risk analysis according to six different flow rates scenario. They matched the obtained results with the urban information system and determined the water levels for each building. They found that the buildings in Ağva are at low and high risk. Khalfallah and Saidi (2018) mapped the precipitation distribution by using the geographical information system (GIS) in the Medjerda basin in Tunisia. They used Hyfran software for the prediction of the flood recurrence period caused by rainfall. They also modeled the floods that occurred in February and March 2015 by using Hec-RAS. When they compared the measurement data with the results of the model, they stated that there was a good correlation. Romali et al. (2018) used the Hec-RAS model in the development of flood maps for the urban area located in Segamat, Malaysian. They used Generalized Pareto, Generalized Extreme Value, LP3, triple-parameter log-normal (LN3), and Weibull distributions to determine the flood recurrence flow rates and the most appropriate distribution with the Kolmogorov-Smirnov (K-S) test. According to the result of the K-S test, they determined the most appropriate distribution as the Generalized Pareto distribution. They created flood maps with Hec-RAS for different recurrence flow rates. When the results were examined, they have seen that the flood areas that occurred with the flood event in the 2011 overlapped the flood areas calculated with the recurrence flow rate of 100 years. Tazın (2018) has developed one- and two-dimensional hydraulic models with Hec-RAS to create a flood hazard map of the Dharla River in the northwestern region of Bangladesh. He made the calibration and the verification of the hydrodynamic models according to the floodwater levels that occurred in 2013 and 2014.

In this study, it is aimed to minimize the possible life and property losses by determining the areas under flood risk in the Küçük Aksu River. Hec-RAS, a hydraulic model based on geographic information systems (GIS), was used to identify flood risk areas. Structural flood analysis was done with the depth maps obtained with analysis that was conducted. Also, the flood risk areas were determined by overlapping the prepared flood risk maps with satellite images, and recommendations were made to reduce possible losses and damages in these areas.

2. Material and Method

2.1. Study Area and Data

Aksu River springs from Akdağ and Davras Mountain near the province of Isparta. Aksu River flows into the southeast direction and mixes with the groundwater in Kovada Lake and then flows into the south by joining the waters coming from Lake Eğirdir in the direction of south of Lower Gökdere Village. Here, it merges with Göksu and pours into the sea from Antalya Bay. Aksu River basin is located between 360 - 380 northern latitudes and 300 – 310 east longitudes. The water catchment area of the Aksu River basin is 8000 km^2. Many karstic springs, which give plenty of water to the limestone layers, feed the Aksu River. Although the water level decreases in the summer and autumn months, there is always plenty of water in the valley. In the winter and spring months, the flow of the stream increases with the downpour and snowmelt. Aksu River flows in the lower parts of the plains and it is widely used for irrigation. There are different types of drainage in the rivers that drain the Aksu River basin, and especially in the lower valley of the Aksu River, the braided drainage type can be seen frequently (Anonymous, 2014).

The Küçük Aksu River begins to flow near Haskızılören Village within the boundaries of Antalya Serik district, and then it passes through the Pınargözü District in this village and joins the Aksu Stream near Akçapınar Village Değirmen Burnu District. The Küçük Aksu River basin is 297 km^2. The Küçük Aksu River chosen as the study area is one of the branches of the Aksu River (Figure 1).

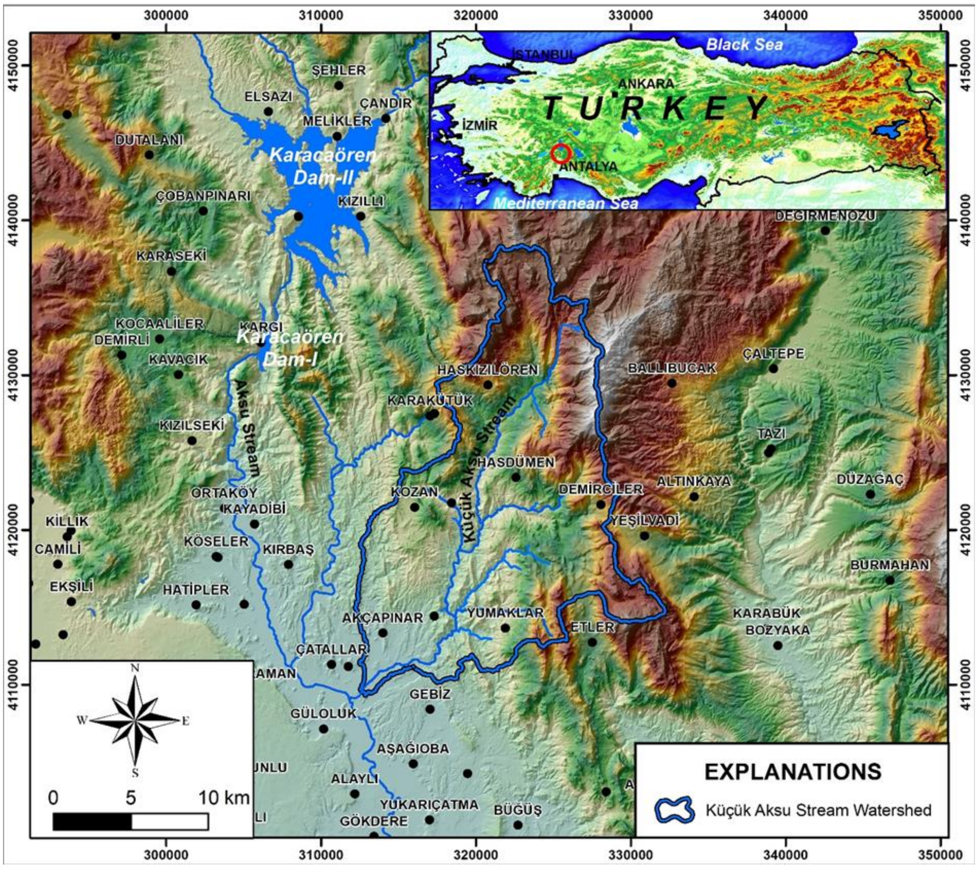

Figure 1. The study area map

The data required for hydraulic modeling includes the flow rates of different recurrence periods, streambed geometry, roughness coefficients, and digital elevation model (DEM) of the river basin. In order to determine the flood flow rates, the annual maximum flow values of the station number of 9-34, which is the only flow measurement station located in the basin and operated by The State Hydraulic Works, were used. The annual mean flow value of the station is 4,19 m^3/s. Figure 2 shows the monthly average flow values observed for 17-year period from 1998 to 2014. The mean rainfall value is 124 mm for the region. The stream bed geometry was obtained from satellite images. Roughness coefficients were determined according to the land usage. The DEM data were produced from 1/25000 scaled topographic maps taken from the General Directorate of Mapping.

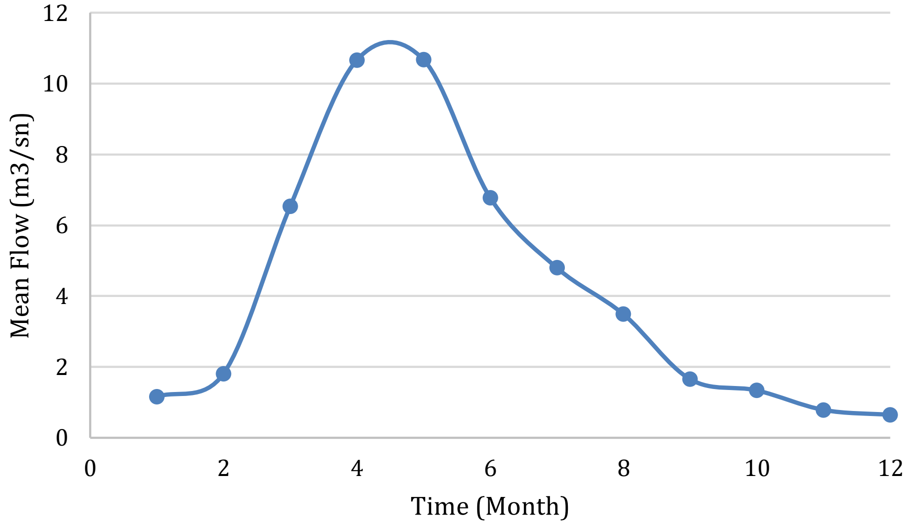

Figure 2. The monthly average flow values

2.2. Hec-RAS

Hec-RAS is a hydraulic model developed by the US Army's Hydrologic Engineering Center (HEC) for the analysis of river channels and the determination of floods in 1964 (Beavers, 1994). Hec-RAS is based on the principle of doing hydrological analysis before the hydraulic model. It is necessary to calculate the flood recurrence flow rates of the stream in determining the flood areas or projecting the flood structures. After the flood hydrographs are obtained, the river channels and their surrounding floodplains, flood areas, and water depths are determined (Usul, 2008).

In one-dimensional models, the behavior of the fluid based on time and space is examined with the continuity equation given in Eq. 1.

$$\frac{\partial V}{\partial t} + \frac{\partial Q}{\partial x} = q_0 \tag{1}$$

It is accepted that the river flow does not change with time and the flow type is expressed as steady flow (Eq. 2).

$$\frac{\partial V}{\partial t} = 0 \tag{2}$$

2.3. Structural Flood Damage Analysis Based on Depth – Damage Factor

In economic terms, the main consideration for flood damage estimation is the concept of depth-damage function or loss functions. These functions are related to the depth of the flood causing the greatest possible economic damage in the flood area. Depth-damage curves, first proposed in the 1960s, are accepted as the standard approach in determining the damages caused by floods nowadays (Smith, 1996).

Structural flood damages are determined in two steps in the areas where the buildings are located. These steps are given in Figure 3 (Pistrika and Jonkman, 2009). The first step is to analyze the structural damage caused by floods. These damages will be determined by flood effects and building resistance. The next step is the economic assessment of physical damages, in other words, the cost calculation of physical damages. In order to transform structural damage into economic estimates, the pre-disaster market value and the replacement cost of the building must be known (Pistrika, 2010).

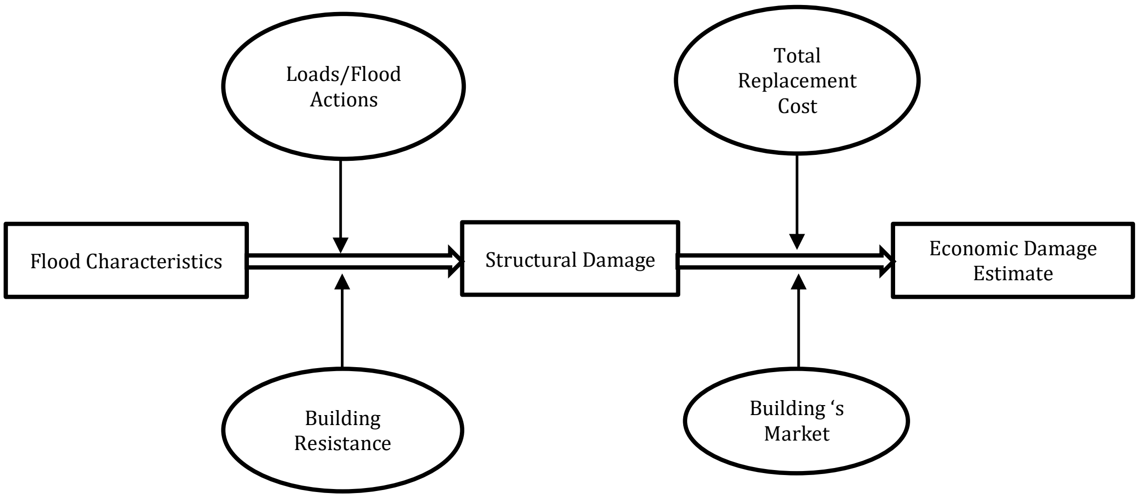

Figure 3. The flow chart of the flood-damage analysis (Pistrika & Jonkman 2009)

There are many depth-damage factor functions available in the literature. In this study, the function proposed by Jonkman et al. (2008), which is a function produced due to floods experienced in many parts of the world, was chosen. The depth-damage factor graph is given in Figure 4. The damage factor indicates what the percentage of the total cost of the buildings exposed to flooding will be damaged by flood (Taş et. al, 2016).

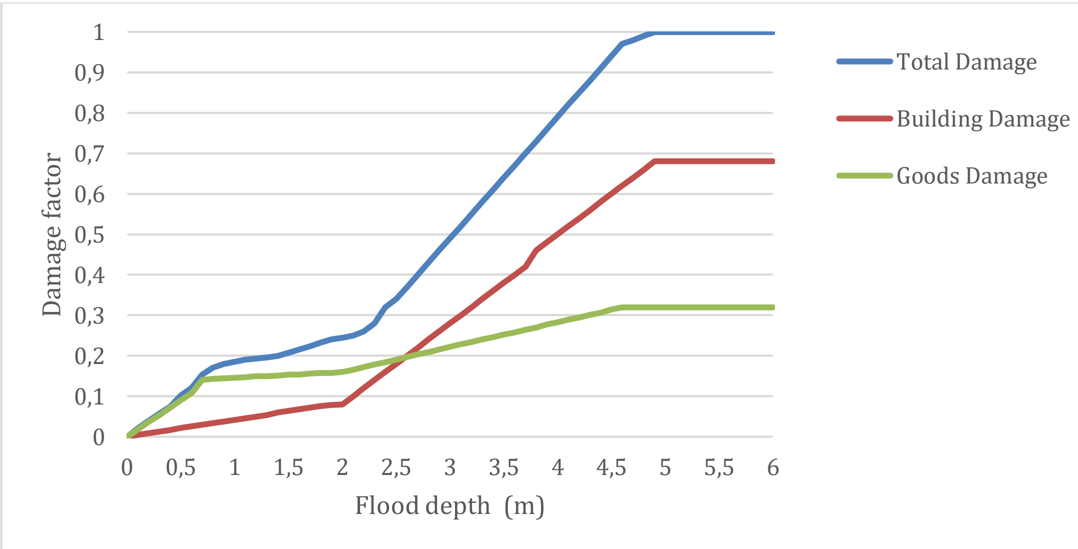

Figure 4. Depth-damage factor graph (Taş et. al 2016)

3. Results and Discussions

Flood recurrence flow rates and stream geometries are needed to develop hydraulic models in the Küçük Aksu River. For this, the results obtained by Baykal and Terzi (2017) in their study for the Küçük Aksu River were used. Baykal and Terzi (2017) calculated the flood recurrence flow rates of the Küçük Aksu River by using different probability distributions. They determined the most appropriate distribution as Log-Pearson Type 3 with Kolmogorov-Smirnov (K-S) test and the graphic method. The recurrence flow rates found with the Log-Pearson Type 3 distribution were given in Table 1. Also, the flow chart of the hydraulic model applied for flood mapping was given in Figure 5.

Table 1. The flood recurrence flow rates

Recurrence Periods	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{500}	Q_{1000}
LP3 Distribution (m^3/sec)	59,02	107,43	140,34	180,70	209,21	236,10	261,48	289,60	315,21

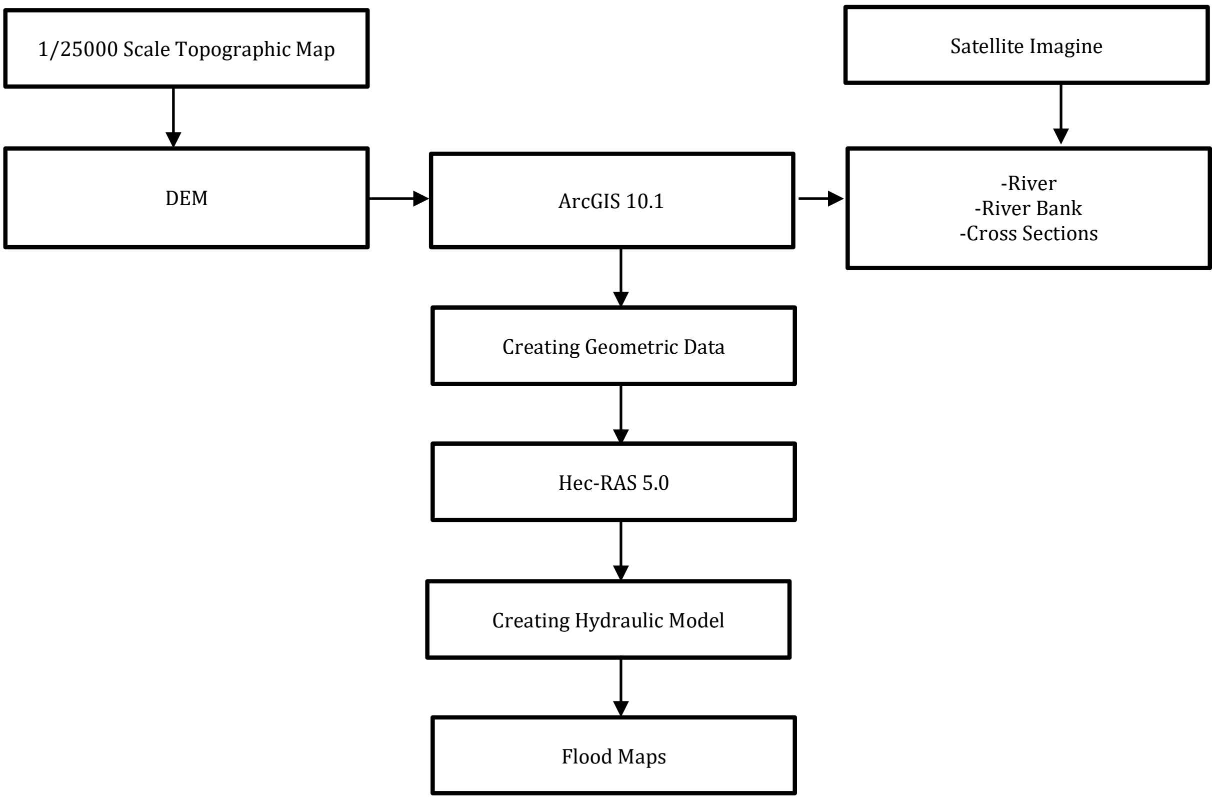

Figure 5. The flow chart of hydraulic model

After entering the required Hec-RAS software, the surface profiles of the Küçük Aksu River were determined for all scenarios. The water surface profiles obtained with Hec-RAS were transferred to the ArcGIS environment and they were mapped. The propagation map of the 100-year recurrence flow rate was given in Figure 6.

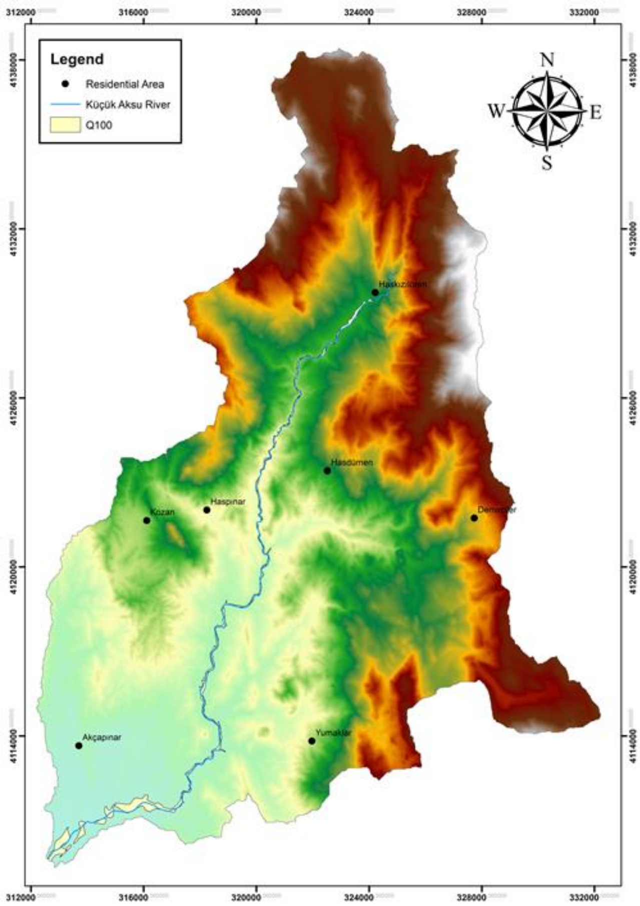

Figure 6. The propagation map of 100-year recurrence flow rate

Examining the distribution map of the 100-year recurrence flow rate, it has been determined that 6.04 ha of the residential area and 33.73 ha of agricultural land are inundated. Inundated settlements and agricultural lands belonging to other recurrence flow rates were given in Table 2 and flood propagation maps were given in Figure 7. The depth maps were also prepared in the study and the depth map of the 100-year flood flow rate was given in Figure 8. The depth maps of other recurrence flow rates were given in Figure 9.

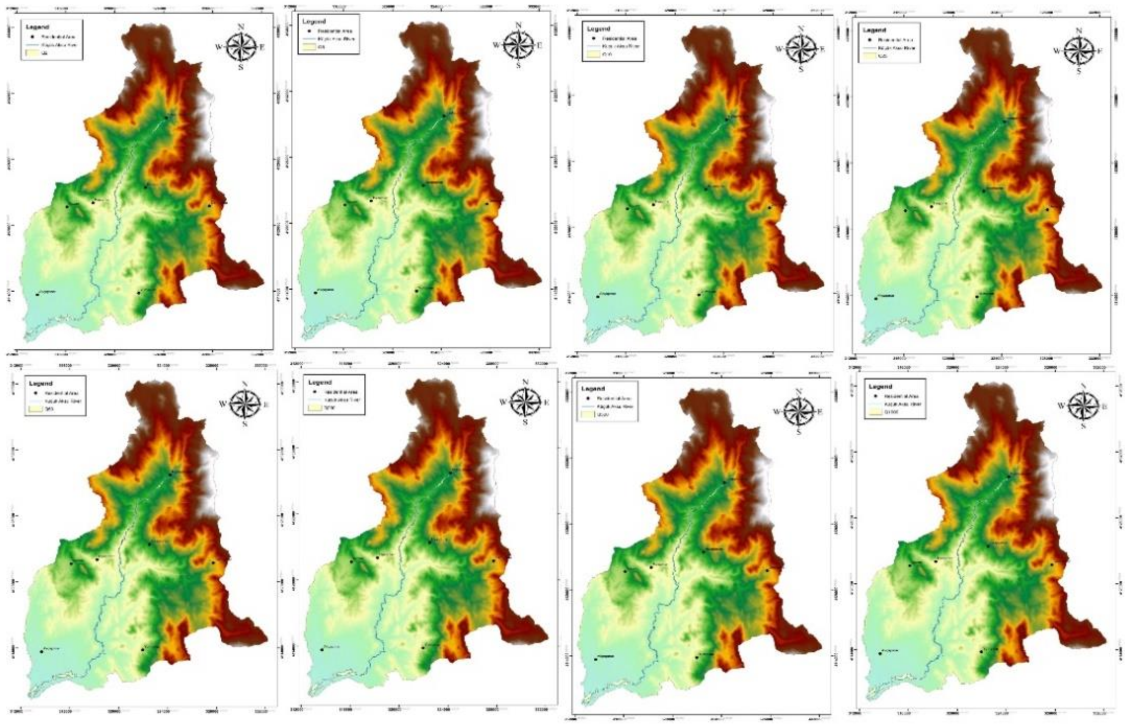

Figure 7. The propagation maps of other recurrence flow rates

Table 2. Underwater areas of different recurrence flow rates

Recurrence Period	Residential Area (ha)	Agricultural Area (ha)
Q_2	5,33	22,27
Q_5	5,56	29,63
Q_{10}	5,63	30,80
Q_{25}	5,80	32,11
Q_{50}	5,91	32,61
Q_{100}	6,04	33,73
Q_{200}	6,09	34,35
Q_{500}	6,10	34,64
Q_{1000}	6,20	35,58

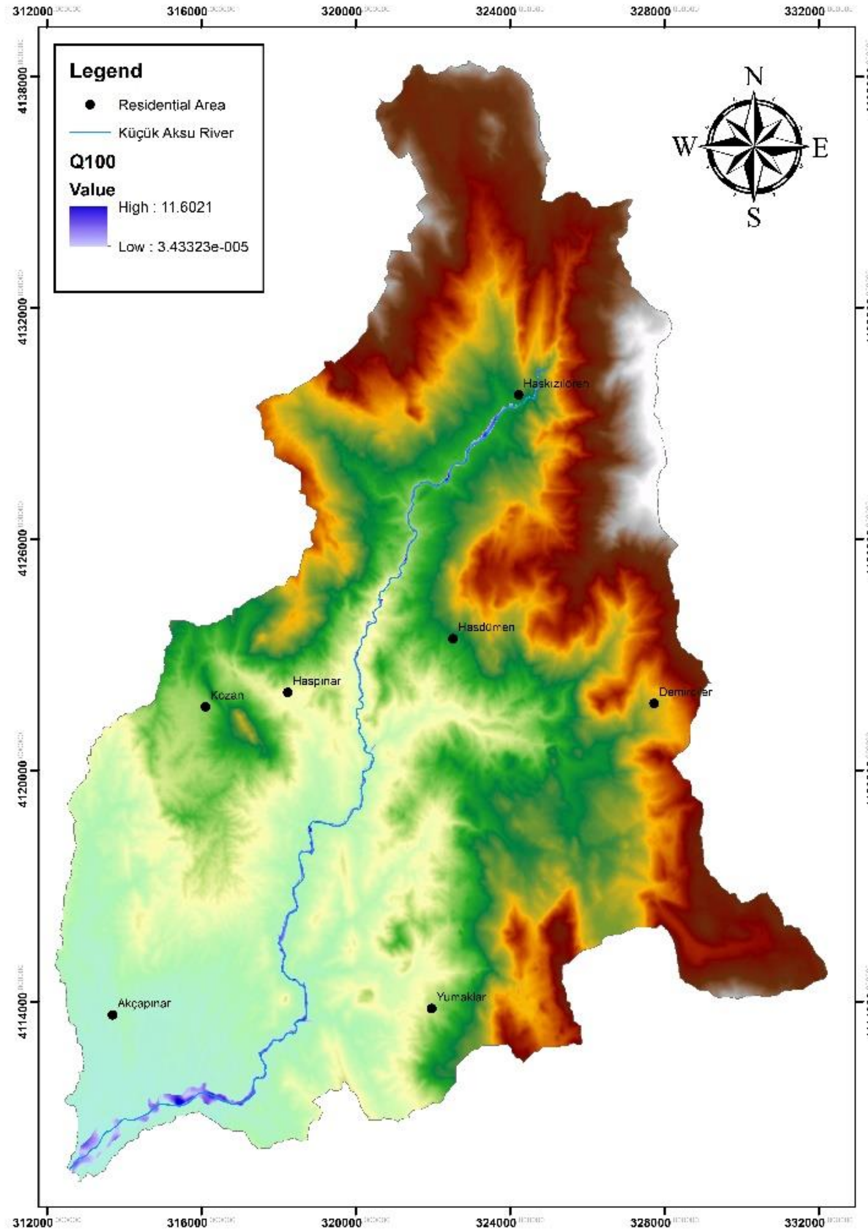

Figure 8. The depth map of 100-year recurrence flow rate

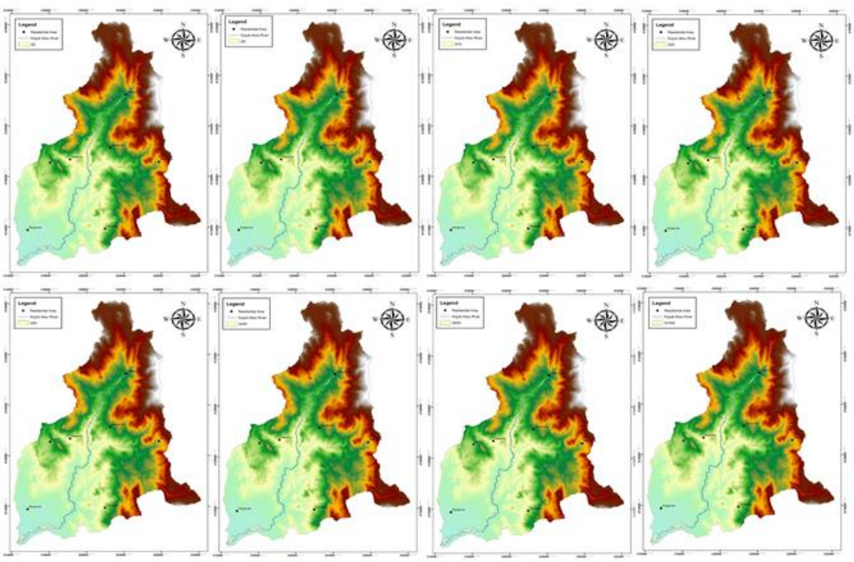

Figure 9. The depth maps of other recurrence flow rates

Calibration is required to demonstrate the suitability of hydraulic models. There are many studies on hydraulic model calibrations in the literature. Horritt and Bates (2002) and Prafulkumar et al. (2011) stated that the roughness coefficients in river and floodplain are limited to a single value for a model calibration. Uçar (2010) said that the model could not be calibrated because there was no rating curve. In this study, since the water level recorded related to the flood events in the region could not be reached, the flood traces observed during the field study were used for model calibration. For this purpose, the flood event occured in Haskızılören Village on October 09, 2011 was used. In this flood incident, six people lost their lives and 20 residences, one health center, and one village headman mansion were demolished (Özmen 2015). Photographs of the damaged buildings that were taken in the field studies carried out in Haskızılören Village in 2015 were given in Figure 10.

Figure 10. View of Haskızılören village after the flood

When the Figure 10 was examined, it could be seen that the water level approximately 3 m from the stream bed during the flood. It was observed that this water level almost coincides with the level which was read from the depth map of the 100-year recurrent flow rate given in Figure 8. In addition, the maximum and average water level of the study area were given in Table 3.

Table 3. Maximum and average water depths

Recurrence Interval (year)	Maximum Water Depth (m)	Mean Water Depth (m)
2	10,72	2,08
5	11,04	2,15
10	11,21	2,18
25	11,40	2,22
50	11,51	2,24
100	11,60	2,27
200	11,68	2,28
500	11,72	2,29
1000	11,93	2,34

In Table 3, it can be seen that the maximum water level from the thalweg was 11.60 m for the 100-year recurrent flow rate along the Küçük Aksu River.

Then, structural flood analysis was performed. The building floor area, the damage factor corresponding to the floodwater depth, the approximate cost of the structure, and the structure depreciation are used while the structural flood analysis depending on the flood water depth was being done. The damage factor was calculated from Figure 5 according to the average water levels. There were semi-masonry buildings and plastic-covered greenhouses in the areas affected by the flood. While the cost of damage for the areas affected by floods was being calculated, the Communiqué published in the Official Gazette No. 31064 on March 10, 2020, was used (MEU 2020). It was decided that the buildings in the study area were in class IV and group B structures and the approximate unit cost of the structure was taken as 1470 TL/m^2. It was decided that the greenhouses were in class I and group

A structures according to the same Communiqué and the approximate unit cost of the structure was used as 185 TL/m^2 (MEU 2020). In addition, the depreciation of these structures was determined according to the chart published in the Official Gazette No. 17886 on February 12, 1982 (MTF 1982). The depreciation rates were taken as 25% for buildings and 45% for greenhouses. The calculated economic losses were given for buildings and greenhouses in Table 4 and 5, respectively.

Table 4. Economic losses for structures

Recurrence Interval (year)	Area (m^2)	Mean Flood Depth (m)	Damage Factor (DF)	Structure Depreciation Rates (%)	Approximate Unit Cost of the Structure (TL/m^2)	Economic Loss (TL)
2	2783	2,08	0,25	0,75	1850	965353
5	3023	2,15	0,26			1090547
10	3521	2,18	0,27			1319055
25	3521	2,22	0,28			1367909
50	3521	2,24	0,28			1367909
100	3807	2,27	0,28			1479020
200	3807	2,28	0,29			1531842
500	3807	2,29	0,29			1531842
1000	3807	2,34	0,30			1584664

Examining Table 4, the total building floor areas in the recurrence interval of 10-, 25- and 50- years and the total building floor areas in the recurrence interval of 100-, 200-, 500- and 1000- year show similarities. These similarities may occur due to the fact that the study area is a rural and scattered residential area. The reason that the damage factors in the recurrence interval of 25, 50, and 100 years and the factors in the 200 and 500-year recurrence interval are the same, may be because of the average flood heights that are very close to each other.

Table 5. Economic losses for greenhouses

Recurrence Interval (year)	Area (m^2)	Mean Flood Depth (m)	Damage Factor (DF)	Structure Depreciation Rates (%)	Approximate Unit Cost of the Structure (TL/m^2)	Economic Loss (TL)
2	6497	2,08	0,25	0,55	210	187601
5	6738	2,15	0,26			202342
10	7325	2,18	0,27			228430
25	7726	2,22	0,28			249859
50	8284	2.24	0,28			267605
100	8944	2,27	0,28			289249
200	9071	2,28	0,29			303833
500	9129	2,29	0,29			305776
1000	10430	2,34	0,30			361400

In Table 5, it can be seen that the economic loss for greenhouses varies between approximately 187000 and 361000 TL. In Table 6, it was given the total economic damages of the structures in the study area due to structural damages. Examining Table 6, it can be seen that the economic loss according to different recurrence intervals vary between approximately 1,152 million and 1,946 million TL.

Table 6. Total economic loss of building and greenhouse

Recurrence Interval (year)	Building Economic Loss (TL)	Greenhouse Economic Loss (TL)	Total Economic Loss (TL)
2	965353	187601	1152954
5	1090547	202342	1292889
10	1319055	228430	1547485
25	1367909	249859	1617768
50	1367909	267605	1635614
100	1479020	289249	1768269
200	1531842	303833	1835675
500	1531842	305776	1837618
1000	1584664	361400	1946064

5. Conclusions

Floods occur as a result of the overflow of rivers from their beds due to the natural events such as excessive precipitation and snow melting. Flood is one of the most common natural disasters after earthquakes in Turkey. According to data from the Turkey Disaster Knowledge Base created by the Disaster and Emergency Management Presidency (AFAD), the 5663 flood events were recorded between 1940 and 2019 in Turkey. In these flood events, hundreds of people lost their lives, thousands of people were injured, and buildings were damaged. Due to these reasons, it is important to estimate floods that cause the most loss of life and property after earthquakes accurately.

In this study, flood models have been developed with Hec-RAS for the Küçük Aksu River in Antalya, Turkey. Hydraulic models were created according to the recurrence flow rates of 2-, 5-, 10-, 25-, 50-, 100-, 200-, 500- and 1000- year, and flood propagation maps and flood depth maps were obtained.

According to the results of hydraulic models, 6.04 ha residential area and 33.73 ha agricultural area are inundated in the Küçük Aksu River basin as a result of the model realized with 100-year flood recurrence flow rate. The maximum water level from the thalweg line, which corresponds to the 100-year flood recurrence flow rate along the stream, has been determined as 11.60 m.

In the flood that occurred in Pınargözü District, which was established on the floodplain on October 09, 2011, it was seen that the water level increased up to 3 m during the field studies. At the same time, it was determined that the flood water level obtained from hydraulic models is around 2-3 m. This situation shows that the result of the hydraulic model coincides with the flood that occurred on October 09, 2011, and it also shows the accuracy of the analyzes.

In this study, also economic damages that may be caused by floods were also calculated according to the recurrence flow rates. The loss was estimated as 1,152 million TL according to the 2-year recurrence flow rate at which the lowest economic loss may occur, while the highest loss was estimated as 1,946 million TL according to the 1000-year recurrence flow rate. Only buildings and greenhouses were considered in the calculation of these values. However, it is thought that the economic loss may increase even more if agricultural areas are included. It is expected that if the study area was urban rather than rural, the economic loss would be much higher.

- By following Law No. 6306 on the "Transformation of Areas Under Disaster Risk", adopted on May 16, 2012, the areas under flood risk can be determined and declared as "risky areas". Thus, the loss of life and property can be prevented by this way. Besides, it would be appropriate to prevent such areas from being used as residential areas.

- Flood protection structures can be built in areas where agricultural lands are located, and flood damage in these regions can be minimized.

- Flood warning systems can be set up in the region, and practical training can be given to the people of the regions about what should be done during the flood.

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Conflict of Interest

No conflict of interest was declared by the authors.

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