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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Flood analysis using the HEC-RAS software for Antakya Altınçay Creek

Antakya Altınçay Deresinin HEC-RAS yazılımı ile taşkın analizi

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ABSTRACT

Flood is one of the most important disasters in the world. Floods, common in our country, are the second disaster after the earthquake in terms of loss of life and property caused by natural disasters and the first among climatic disasters. The district of Antakya is located where streamflow has a high flow coefficient. Because of flooding in Altınçay Creek which flows through the center of Antakya into the Orontes River, flood studies need to be carried out and the necessary precautions taken to prevent flooding. In this study, peak discharges for 2, 5, 10, 25, 50, and 100-year return periods of Altınçay Creek passing through residential areas in Antakya were determined by SCS and DSI synthetic methods. Using these estimated peak discharges the water profile along the Altınçay Creek route has been simulated using HEC-RAS software, and the flood risk areas were determined on cross-sections basis. As a result, flood risk was not observed in peak discharge for return periods of 2, 5 and 10 years. However, flood events were observed at 16, 51, and 73 different cross sections in peak discharges for return periods of 25, 50, and 100 years respectively. To reduce flood damage, it was suggested that the cross-sectional areas having flood risk must be increased.

ÖZET

Taşkın, dünyanın en önemli afetlerinden biridir. Ülkemizde yaygın olarak görülen taşkınlar, doğal afetlerin neden olduğu can ve mal kaybı açısından depremden sonra ikinci, iklimsel afetler arasında ise birinci sırada yer almaktadır. Antakya ilçesi, eğimi ve akış katsayısı yüksek akarsuların olduğu bir konumdadır. Antakya şehir merkezinden geçerek Asi Nehri’ne dökülen Altınçay Deresi bu akarsulardan biridir ve meydana gelen taşkınlar nedeniyle taşkın etütlerinin yapılması ve taşkından korunmak için gerekli önlemlerin alınması gerekmektedir. Bu çalışmada, Antakya'daki yerleşim alanlarından geçen Altınçay Deresi'nin 2, 5, 10, 25, 50 ve 100 yıllık dönüş periyotlarına ait pik debileri SCS ve DSİ sentetik yöntemleri ile belirlenmiştir. Bu tahmini pik taşkın debileri HEC-RAS yazılımında kullanılarak benzetimi yapılmış ve Altınçay Deresi güzergahı boyunca seçilen akarsu kesitlerinden su profili derinliği ve taşkın risk alanları kesit konumlarına göre belirlenmiştir. Sonuç olarak, 2, 5 ve 10 yıllık dönüş periyotlarına sahip pik debilerde taşkın riski gözlenmemiş, ancak 25, 50 ve 100 yıllık dönüş periyotlarına sahip pik debilerde sırasıyla 16, 51 ve 73 farklı istasyonda taşkın olayları gözlenmiştir. Taşkın zararını azaltmak için taşkın riski taşıyan kesit alanlarının artırılması önerilmiştir.

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INTRODUCTION

Floods are a significant natural disaster, causing extensive damage to residential areas, infrastructure, agricultural lands, and local fauna. These events disrupt economic and social activities in affected regions. Floods are ranked second after earthquakes and first among climatic disasters regarding loss of life, property damage, and financial losses caused by natural disasters (Blöschl et al., 2020). Ranking as the second most destructive natural hazard after earthquakes, floods have been a significant concern in Türkiye. The Turkish Disaster Database documented 1076 flood events between 1960 and 2014, causing 795 fatalities and 800 million USD in economic losses (Koç et al., 2020). Türkiye experiences a notable frequency of flooding, with an average of 22 flood events and 19 deaths occurring annually (Saber & Yılmaz, 2018). Human activities such as improper land use, unauthorized settlements along rivers and streams, and erosion significantly contribute to floods (Song et al., 2020). In addition to human interventions, climate change and forest fires are another significant reason for the recent increase in flood frequency. Changes in precipitation patterns, particularly the increase in rainfall intensity, are expected to exacerbate flooding due to climate change (Arnell & Gosling, 2014). Therefore, determining flood risk areas by simulation of defined streamflow is a critical issue for flood management in terms of reducing flood risk (Luu et al., 2020; Cai et al., 2021; Dong et al., 2022; Woldegebrael et al., 2022; Olanrewaju & Reddy, 2022).

Flood data analysis forms the foundation of flood risk assessment, involving the collection, interpretation, and utilization of data related to past flood events, hydrological conditions, and geographical features (Luu & Meding, 2018). Analyzing flood data allows for the identification of patterns, trends, and potential risks, which contributes to a more comprehensive understanding of flood dynamics and vulnerabilities (Wang et al., 2020). This data-driven approach enables researchers and policymakers to assess the spatial distribution of flood risk, evaluate the effectiveness of existing flood management strategies, and develop targeted interventions to enhance resilience (Chen et al., 2022). To minimize the impact of flooding, researchers are using various models and software for the identification and prediction of flood inundation zones. One of these software programs is the Hydrologic Engineering Center River Analysis System (HEC-RAS) model. HEC-RAS is a widespread software developed by the US Army Corps of Engineers and known for its effectiveness in flood studies (Irvem & Ozbuldu, 2020). Researchers have successfully used HEC-RAS in various flood modeling scenarios, including analyzing flood data from different regions using 1D and 2D numerical simulations (Patel & Gundaliya, 2016; Manina et al., 2020; Oğraş & Önen, 2020; Razi et al., 2022; Milišić & Hadžić, 2023).

Changes in climate and precipitation regimes in recent years have led to more frequent and severe flood events. To prevent flooding, it is necessary to take various protection measures and to continue increasing efforts to reduce its destructive effects. Antakya district is located in a region with high slopes and downstream of stream beds with high flow coefficients. The increasing number of settlements in the region, coupled with forest fires in the river basins, particularly the devastating fire in 2013, have significantly reduced forest cover. For these reasons, it is obvious that the runoff flows after rainfall will increase. It is necessary to carry out flood studies and take necessary precautions for the discharge channels that flow through to the Orontes River in Antakya. The importance of the study lies in its contribution for preventing the loss of life and property by minimizing the destructive effects of floods on settlements and agricultural areas. In high-risk areas such as Antakya, flood management and risk analysis studies are critical for the sustainability of economic and social activities in the region. In this context, the results of the study will provide guidance for local governments and relevant institutions in combating floods.

The aim of this study is to determine the flood flows of the Altınçay Creek passing through residential areas in Antakya for different return periods and to simulate the water profile along the stream route using HEC-RAS software. In line with the simulation results obtained, it is aimed to determine the flood risk areas and to reveal the measures that can be taken to reduce this risk.

MATERIALS and METHODS

Study area

This study was performed in the Altınçay Creek Basin, which is located within the borders of Antakya district of Hatay province and has an area of 12 km^2. The length of the Altınçay Creek is 8.2 km and as a result of the reclamation works carried out by the State Hydraulic Works (DSI) of the Republic of Türkiye in 2011, dikes were constructed on both sides of the stream, and it was transformed into a 6.2 km long discharge channel. The location of the Altınçay Creek Basin is given in Figure 1. In the study, a topographic map and satellite images of the river basin were used. The boundary of the basin, the route of the streams, the slope of the stream, and the locations of the art structures were determined with ArcGIS and HEC-RAS software were used for hydraulic modeling.

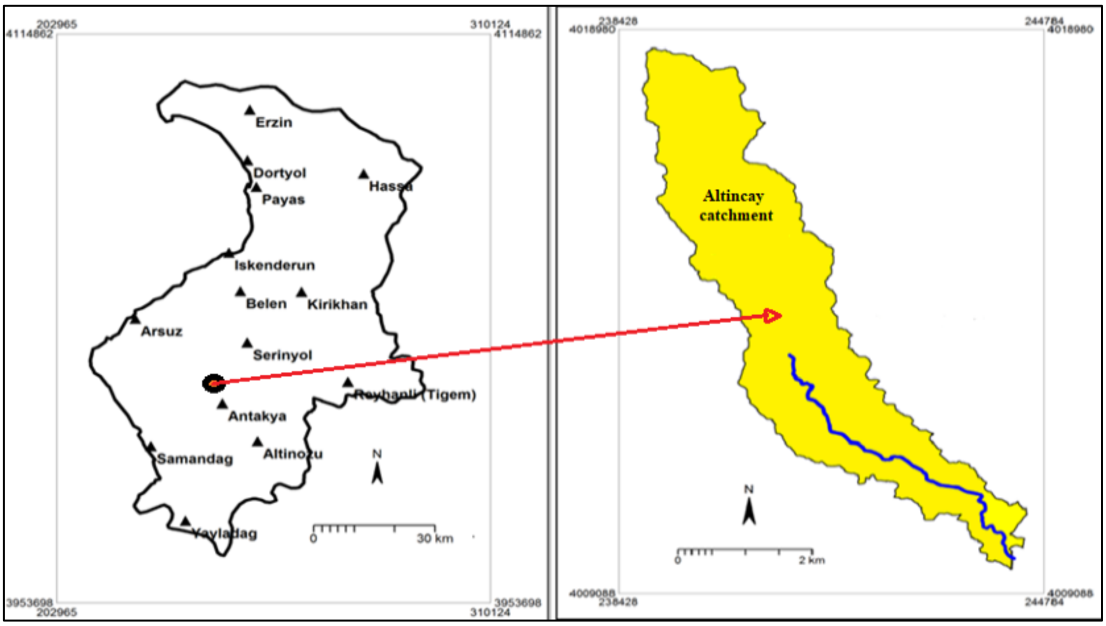

Figure 1. The location of the study area

Şekil 1. Çalışma alanı konumu

The HEC-RAS software

The Hydrologic Engineering Center's River Analysis System (HEC-RAS), developed by the American Hydrologic Engineering Center, is a one-dimensional simulation model designed to determine water surface elevations in channels, rivers, and surrounding floodplains (HEC-RAS, 2010).

Determination of surface runoff from precipitation

In the absence of a flow measurement station for Altınçay Creek, flow estimates were derived from precipitation data using the Soil Conservation Service (SCS) runoff method. Long-term precipitation records were obtained from the Antakya meteorological station, the nearest representative station for the stream basin. In this study, the SCS dimensionless synthetic unit hydrograph method developed by the U.S. Soil Conservation Service and preferred due to its ease and applicability in determining runoff from precipitation was used. In the SCS method surface run-off can be calculated using Equation 1 (Tülücü, 2002).

$$Q=\frac{\left[P-\left(\frac{5080}{CN}-50.8\right)\right]^2}{\left[P-\left(\frac{20320}{CN}-203.2\right)\right]} \qquad \textbf{Eq.(1)}$$

Where, Q, actual direct runoff, mm; P, total storm rainfall, mm; CN is curve number (dimensionless). Empirical analyses have shown that the CN value is a function of soil group, surface cover and previous moisture status. When determining the CN value in very large basins, the large basin can be divided into sub-basins to create more homogeneous conditions in terms of soil properties and vegetation cover. The CN value can be estimated more easily for each sub-basin and a single CN value can be found for the whole basin by taking the weighted average of these values according to the terrain (Tülücü, 2002; Akgül & Çetin, 2016).

DSI synthetic hydrograph method

In case of lack of the flow data in any basin, the unit hydrograph theory can be used to estimate peak flow (Yi et al., 2022). In this study, DSI synthetic method was used for peak flow estimation. DSI synthetic unit hydrograph method in areas with a rainfall area less than 1000 km^2 gives better results than other methods (Demir & Ülke Keskin, 2022). DSI synthetic method is based on the SCS dimensionless unit hydrograph method. In the DSI synthetic method, the runoff yield of a rainfall of a certain duration is calculated by Equation 2. Probability analysis of these data yielded rainfall amounts corresponding to returned periods of 2, 5, 10, 25, 50, and 100 years. Utilizing the DSI synthetic unit hydrograph method, peak discharges for different return periods were determined.

$$Q_p = q_p \times A \qquad \textbf{Eq.(2)}$$

Where, A is the basin area (km^2) and q_p is the flow rate per unit area at a flow height of 1 mm. q_p is calculated by Equation 3.

$$q_p = \frac{414}{A^{0.225} E^{0.16}} \qquad \textbf{Eq.(3)}$$

Where, E is a parameter and is calculated with Equation 4.

$$E = \frac{L \times L_C}{\sqrt{s}} \qquad \textbf{Eq.(4)}$$

Where, L is the length of the main watercourse (km), L_C is the watercourse distance between the projection of the basin center of gravity on the main watercourse and the basin outlet point (km) and S is the basin harmonic slope (%). The volume of water (m^3) created from the total area by one mm of runoff height is calculated by Equation 5.

$$V_b = A \times h \qquad \textbf{Eq.(5)}$$

Where, h is the flow height (mm) and A is the catchment area (km^2). The base time of the hydrograph (h) is calculated by Equation 6.

$$T = 3.65 \frac{Vb}{Qp} \qquad \textbf{Eq.(6)}$$

The time to peak of the hydrograph is calculated by Equation 7 and harmonic slope is calculated by Equation 8.

$$Tp = \frac{Tb}{5} \qquad \textbf{Eq.(7)}$$

$$s = \left[\frac{n}{\sum_{i=1}^{n} \frac{1}{\sqrt{S_i}}}\right]^2 \qquad \textbf{Eq.(8)}$$

Where, S is the harmonic slope, n is the number of river parts along the channel.

Determination of channel sections and roughness coefficient

The cross-sections to be defined for the Altınçay Creek were determined as 300 control cross-sections to represent the places where the flow, slope, cross-sectional shape or roughness changes along the channel, where the dikes and bridges start and end. These control sections were defined as stations. The distances between stations vary between 20 meters and 60 meters in terms of changes in channel geometry. Roughness is one of the factors affecting the flow velocity of water in streams and channels. As a result of numerous studies, roughness coefficients have been obtained for different characteristics of the channels. This coefficient must be defined in HEC-RAS for simulation. Roughness coefficients according to the characteristics of the channels taken from the literature (Chin, 2006). In this study, the roughness coefficient was taken as 0.020 since the Altınçay Creek is a reinforced concrete structure and there is no vegetation in the channel.

Calculation of water profile in channel

In the HEC-RAS software, the water surface profiles are calculated by a method called the standard step method, which is based on the repeated solution of the energy equation from one cross-section to another (Sarhadi et al., 2012). The energy equation used in HEC-RAS software is given in Equation 9.

$$Z_2 - Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e \qquad \textbf{Eq.(9)}$$

Where, Z_1 and Z_2 represent the main channel bottom height, Y_1 and Y_2 represent the cross-sectional flow depth, V_1 and V_2 represent the average velocity, α_1 and α_2 represent the velocity coefficient, g represents the gravitational acceleration, and h_e represents the energy loss height (Ardıçlıoğlu M., 2007).

RESULTS and DISCUSSIONS

Defining channel geometry of Altınçay Creek

To create channel geometry, the direction of water flow, coordinate information of the stations, channel cross-section data, channel length, channel roughness coefficients and distances between stations were defined as basic geometric data in the HEC-RAS software as a result of the survey measurements using laser level.

Altınçay Creek is a stream bed with very different geometric cross-sections, a very small part of which is a stone wall, and all other parts have reinforced concrete dikes on both sides. Reinforced concrete walls were constructed by DSI in 2011 for flood protection purposes to ensure that water flows in a certain place and direction. The cross sections along the channel differ in terms of area and shape. The channel sections do not show a uniform structure in general from the downstream, i.e. the part that flows into the Orontes River, to the origin. According to the measurement results, it was observed that the bottom width of the channel in the Altınçay Creek varies between 3 meters and 14 meters, while the channel depth is between 3 meters and 10 meters. Figure 2 shows the cross-section geometry of sections 262 and 266, As seen in figure sections 263 and 264 have the narrowest cross-section of the channel. Compared to the other sections, the cross-sectional area is about 50% less. In most of the channels, the dike heights are not equal on both sides of the channel.

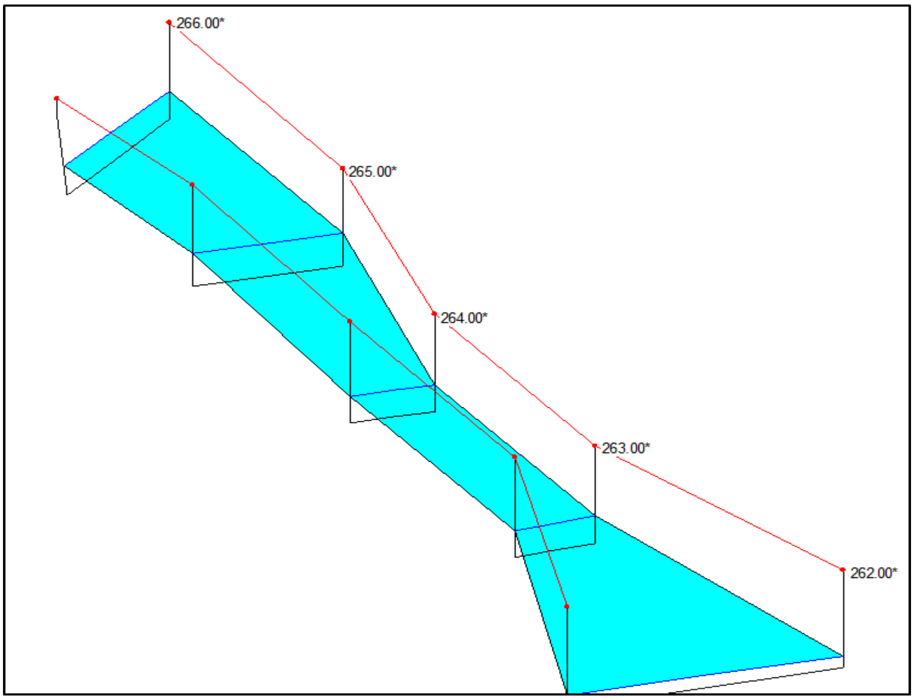

Figure 2. Cross sections between 262-266

Şekil 2. Kanalın 262 ve 266 arasındaki kesitleri

Determination of discharges at cross-sections

Flow measurements were made on 11.12.2018, 27.12.2018 and 16.01.2019, on days with relatively heavy precipitation. The measurements were made at 3 different points, at stations 11 near the downstream, 123 in the middle and 265 near the upstream nearly at the same time. Since the results of the flow measurement made on 11.12.2018 were close to the discharge of return period of 2 years (10.9 m^3/s), the possible amounts of the flood flows obtained for the basin outlet at other stations were determined according to these measurement results which is given Table 1. There is only one historical measured data for the creek taken during flood events in 1998 was 88 m^3/s.

Table 1. Measured discharges at three different locations along the channel

Çizelge 1. Kanal boyunca üç farklı noktadan ölçülen debi miktarları

Date		**Cross-sections**		
		267	**123**	**11**
11.12.2018	Rotation	3533	8006	10270
	Velocity (m/s)	1.58	3.58	4.6
	Depth (m)	0.16	0.18	0.25
	Discharge (m^3/s)	**2.83**	**6.30**	**9.2**
27.12.2018	Rotation	3634	12014	16464
	Velocity (m/s)	1.62	5.38	3.08
	Depth (m)	5.38	0.21	11.05
	Discharge (m^3/s)	**7.37**	**11.05**	**15.92**
19.01.2019	Rotation	3721	12903	17372
	Velocity (m/s)	1.66	5.78	7.78
	Depth (m)	0.18	0.22	0.28
	Discharge (m^3/s)	**3.35**	**12.43**	**17.42**

In order to determine the flows corresponding to other stations according to the flows obtained from three stations, regression analysis was performed as seen in Figure 3. Flow values are linear. Discharges for returned periods of 2, 5, 10, 25, 50 and 100 years all stations along the channel were determined using the calculated regression equation (Figure 3).

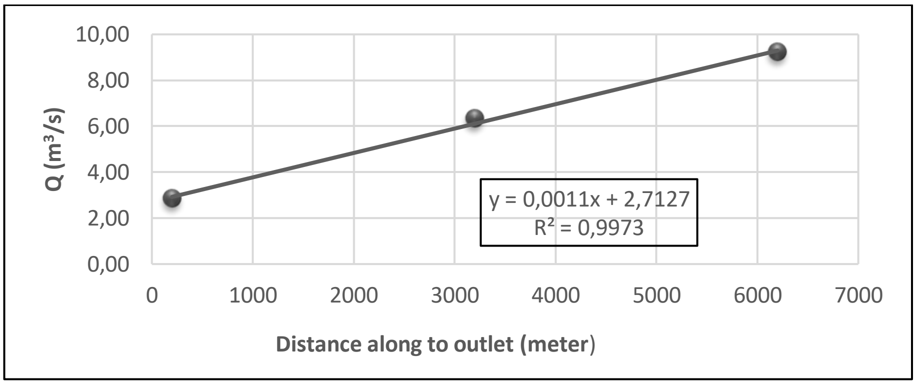

Figure 3. Regression results along the channel

Şekil 3. Kanal uzunluğu boyunca regresyon sonuçları

DSI synthetic hydrograph method results

In order to calculate the flood flow synthetically with the DSI method, the hypsometric slope of the stream must be known. As a result of the calculation, the harmonic slope for Altınçay Creek was found 2.1%. The unit hydrograph developed according to the calculation results is given in Figure 4. The peak flow rate and time to peak of the unit hydrograph was calculated as 1.17 $m^3/s/mm$ and 2.07 hours respectively.

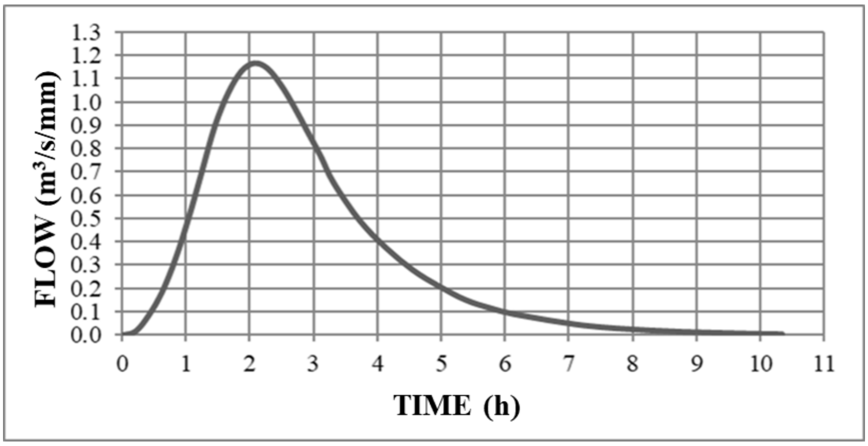

Figure 4. Unit hydrograph for the Altınçay Creek

Şekil 4. Altınçay deresi birim hidrografı

Determination of peak discharges for different return periods

24-hour maximum precipitation data for different returned periods were obtained from Antakya meteorological station. In the Altınçay Creek catchment, the CN value was obtained as 79 for study area from previous study done by Keskinkılıç (2007). Precipitation and CN values used in Equation 1 to calculate surface runoff. According to the unit hydrograph values obtained from DSI synthetic unit hydrograph method, flood hydrographs were developed for return periods of 2 years (Q_2), 5 years (Q_5), 10 years (Q_{10}), 25 years (Q_{25}), 50 years (Q_{50}) and 100 years (Q_{100}). The flood hydrographs developed for Altınçay Creek are given in Figure 5.

Bozdoğan and Canpolat (2024) studied to determine peak discharges for flood studies using HEC-RAS in the Delibekirli Stream in Kırıkhan, Hatay. Peak discharge in unit hydrograph was calculated 3.18 m^3/s. They found peak discharges 89.41 m^3/s for return periods of 100 years. Results shows that characteristics of catchments are affected peak discharge. They use peak discharges for different return periods in HEC-RAS steady flow analysis. They explained that the works for the river channel should be designed based on at least 500-year flood flow (124,36 m^3 /s).

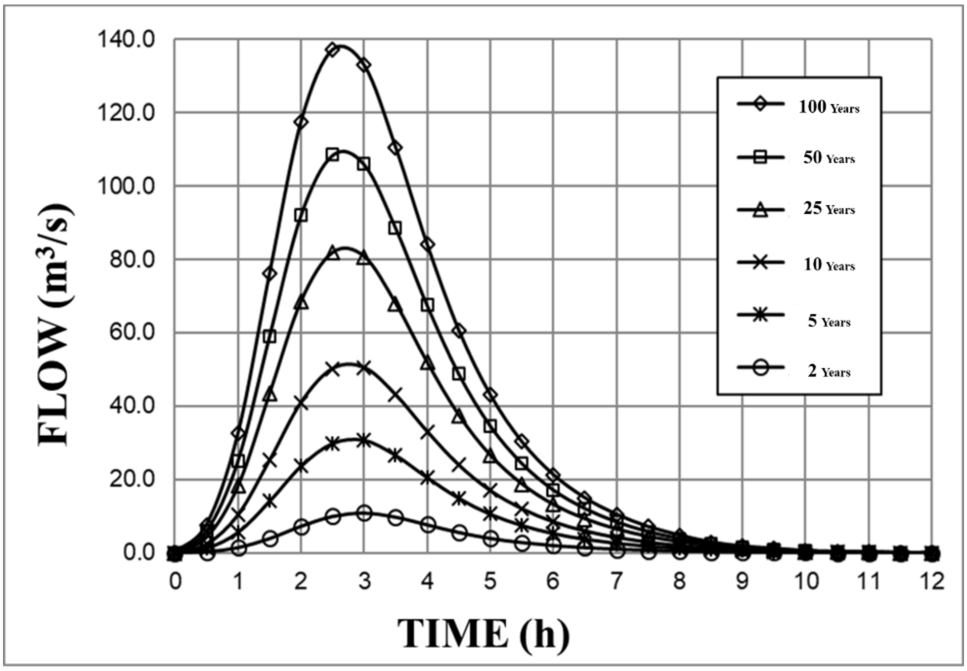

Figure 5. Flood hydrographs of the Altınçay Creek for different returned periods
Şekil 5. Altınçay deresinin farklı yienelenme yılları için taşkın hidrografları

Simulation results using peak flow rate for return periods of 2, 5, and 10 years

The two-year returned periods flood flow rate was calculated as 10.9 m^3/s. This flow rate calculated by the DSI method was simulated according to the regression line with the measured flow rates at the outlet of the basin and the flow rates for each station along the channel were defined in the HEC-RAS software. As a result of the simulation, water profiles were obtained for 300 different stations from the upstream to the downstream of the Altınçay Creek. No flood event was observed between stations 0 and 300 using the peak discharges for return period of 2 years.

Simulation results using peak flow rate for return periods of 25 years

Calculated peak discharges (81.7 m^3/s) for the return periods of 25 years was entered into the HEC-RAS software as steady flow data, the water level approached the critical water level at many stations and 16 stations experienced flood events. Figure 6 shows the simulation results for stations between 0-11, 16-36 and 45-58. Among the cross-sections between 0-11, It was seen that 4 and 7 have maximum water depth exceeding channel height. The main reason for the flooding at these stations can be explained as the narrowing of the channel sections of 2- 3 and 5-6. Cross-sections 17, 20, 21, 29, 30, 31 were observed flood between stations 16-36. Floods were observed at all stations between 45-58.

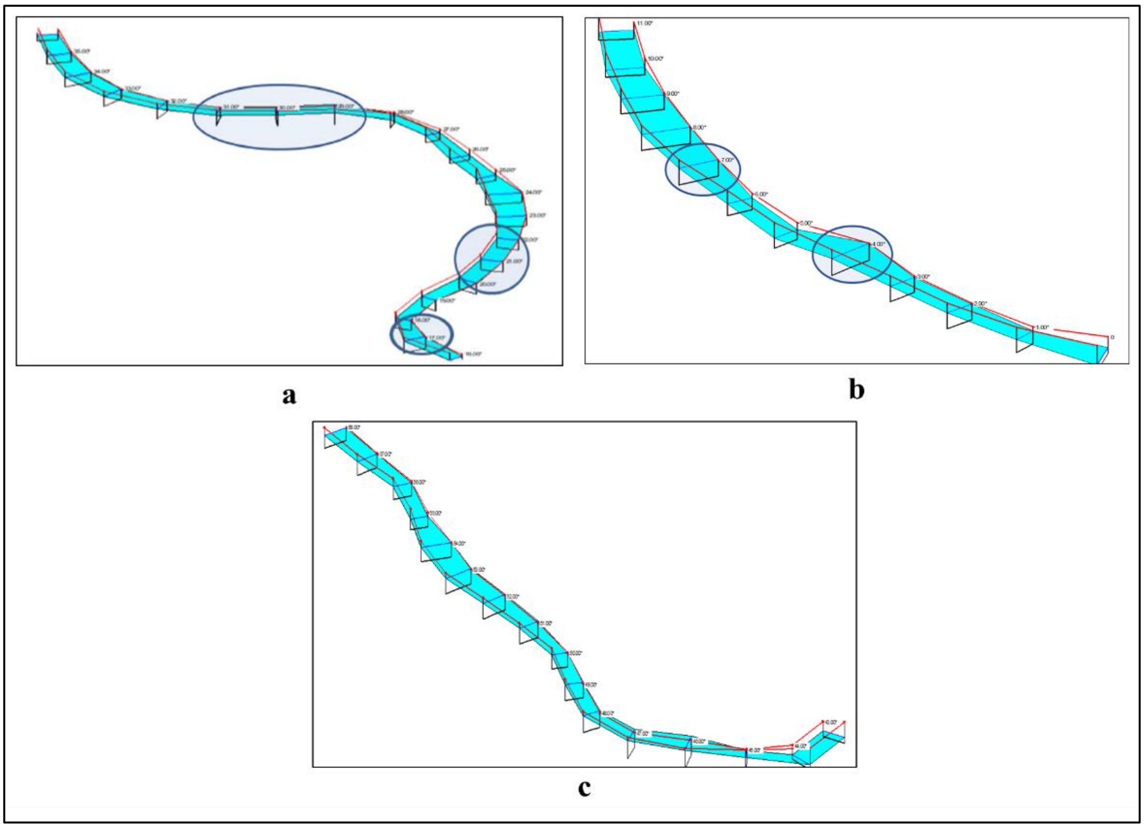

Figure 6. Water profiles for sections a) 0-11, b) 16-36 and c) 45-58 peak flow for the return periods of 25 years

Şekil 6. 25 yıl yinelenmeli taşkın debisinde a) 0-11, b) 16-36, c) 45-58 nolu kesitlerde su profilleri

Simulation results using peak flow rate for return periods of 50 years

Peak discharge for the return period of 50 years (108.4 m^3/s) was entered into the HEC-RAS software as steady flow data, and it was observed that 51 stations downstream experienced flood events. Figure 7 shows the stations subjected to flooding between cross-sections 0-40 and 40-70.

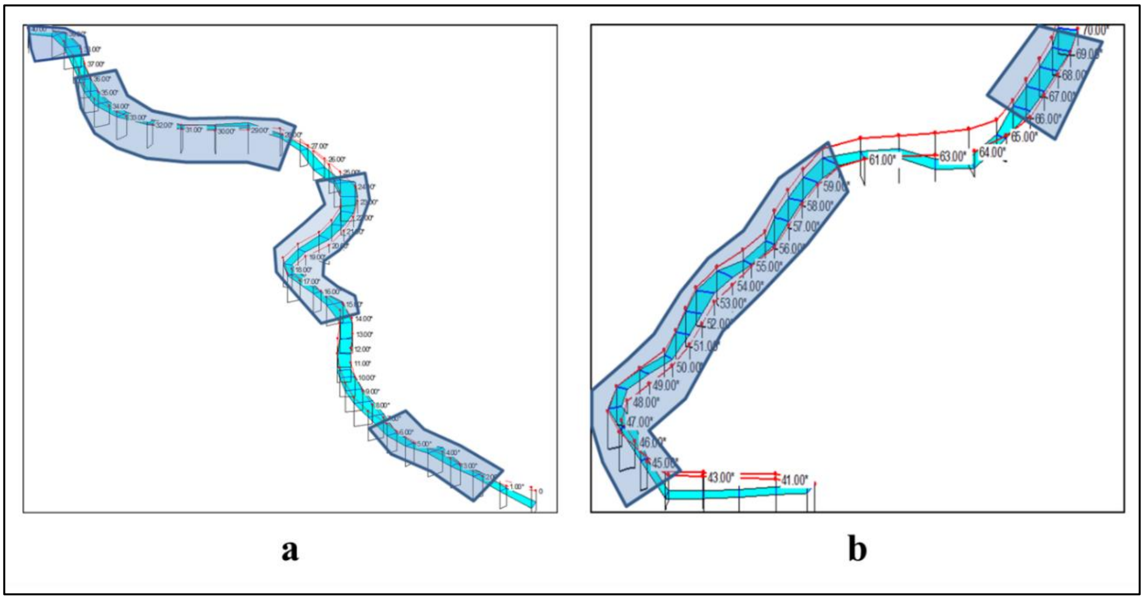

Figure 7. Water profiles for stations a) 0-40 and b) 40-70 at peak flow for the return periods of 50 years

Şekil 7. 50 yıl yinelenmeli taşkın debisinde a) 0-40 and b) 40-70 nolu kesitler için su profilleri

Simulation results using peak flow rate for return periods of 100 years

Peak discharge for the return periods of 100 years (137 m^3/s) was entered into the HEC-RAS software as steady flow data. As a result of the simulation, naturally the highest number of flood events was observed at 71 cross-sections at this flow rate. Figure 8 shows the areas exposed to flooding between cross-sections 0-12, 12-75, 90-105 and 263-271.

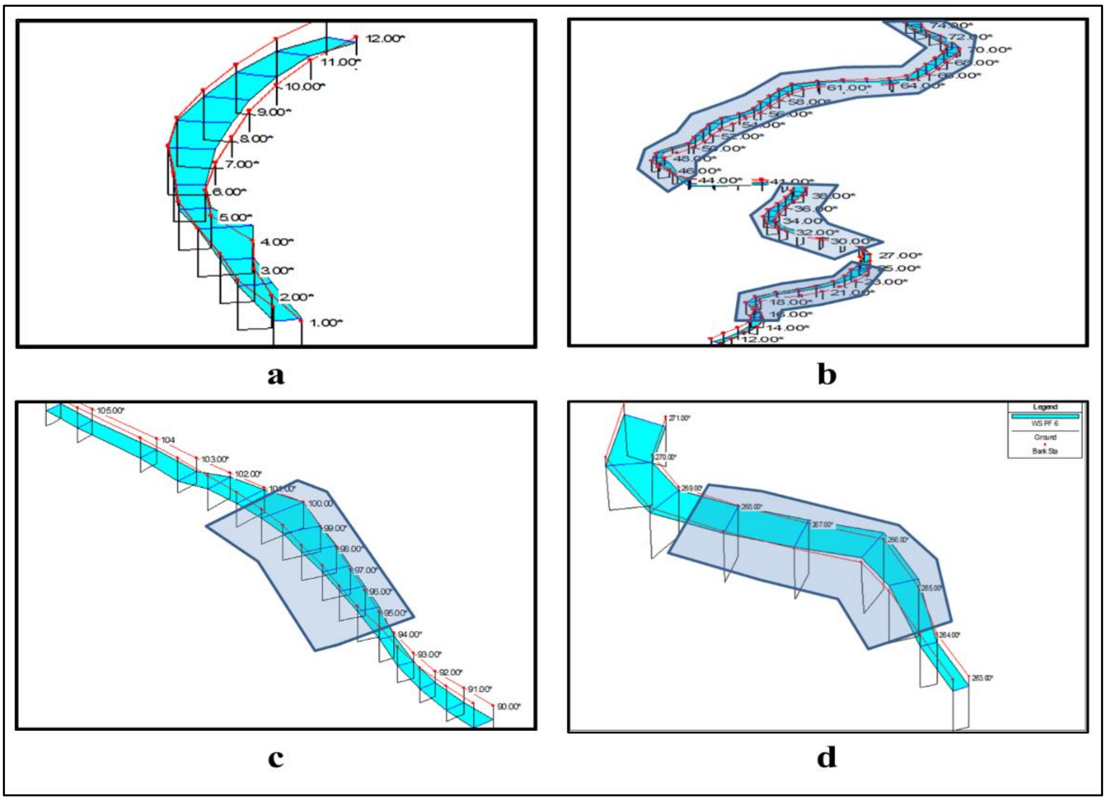

Figure 8. Water profiles for stations a) 0-12, b) 12-75, c) 90-105 and d) 263-271 for the return periods of 100 years

Şekil 8. 100 yıl yinelenmeli taşkın debisinde a) 0-12, b) 12-75, c) 90-105 ve d) 263-271 nolu kesitler için su profilleri

The downstream part of the Altınçay Creek is a densely populated area. Due to the risk of loss of life and property, the channel section should be designed for at least 100-year flood flow. In these areas, the channel bottom length should be 12 meters. The upstream part of Altınçay Creek is less dense in terms of settlement than the downstream part. There was no flood risk in this area for peak discharges of 2, 5, 10, 25 and 50 years returned periods flood flows, but at 100-year peak discharge, flooding was observed at stations 265-268. It was determined that the flooding at these stations was caused by the sudden narrowing of the cross-section, and it is recommended that the channel bottom width of the cross-section at stations 263 and 264 should be 12 meters.

In conclusion, flood-prone areas in the Altınçay Creek have been identified through simulations conducted using the HEC-RAS software. No flood risk was observed in the channel for flood discharges with the returned periods of 2, 5, and 10 years. However, peak discharge for the return period of 25 years indicated that the discharge exceeded the channel capacity at 26 stations in the downstream section where settlement is dense. peak discharge for the return period of 50 years, 51 stations were at risk, and peak discharge for the return period of 100 years, 71 stations were identified as flood prone. The study found that the cross-sections of the Altınçay Creek, which passes through residential areas, have been narrowed by construction, resulting in insufficient cross-sections in some areas. This is particularly critical in the densely populated downstream regions where flood risk is significant. The large forest area effected by 2012 forest fire and increased the surface runoff capacity of the soil so in this area risk of flood further heightening. Also, in this area waste disposal, debris, industrial, and domestic waste in the streambed, along with sediment accumulation and vegetation growth, narrow the streambed and slow water flow, exacerbating the risk of flooding. Simulation results recommend recalculating and widening the narrow sections of the streambed to accommodate at least a peak discharge for the return periods of 100 years.

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STATEMENT OF CONFLICT OF INTEREST

The authors declare no conflict of interest for this study.

AUTHOR'S CONTRIBUTIONS

The contribution of the authors is equal.

STATEMENT OF ETHICS CONSENT

Ethical approval is not required as there are no studies with human or animal subjects in this article.

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