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Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi 2024; 10 (3): 129-147 Araştırma Makalesi/Research Article

# Assessment of Potential Flood Magnitude in the Endek Stream Basin (Horasan-Erzurum) Using Unit Hydrographs

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**Abstract**

The primary objective of this research is to ascertain the potential flood risk in the Endek Stream Basin, which extends roughly north-south in the Horasan district of Erzurum, and its tributary, the Kırmızı Stream Basin, utilizing unit hydrographs. The study employed ArcGIS Pro software to determine the basin's hydrological characteristics and estimate the discharge volume at the basin outlet. Initially, a 25-meter resolution Digital Elevation Model (DEM) of the basin was procured. Using this model and hydrrological tools, flow direction, flow accumulation, and slope maps of the streams within the basin were generated. These primary datasets facilitated the development of a spatially variable velocity field independent of discharge.

In this study, in the subsequent phase, a flow time map was created, delineating the duration required for water to travel from any point in the basin to its outlet. During the preparation of this map, 30-minute intervals were deemed significant for flood occurrence, and accordingly, the basins were divided into isochrone regions. Utilizing data derived from these analyses, unit hydrograph curves were employed to determine the discharge variation at the basin outlet following a potential sudden precipitation event. These curves were produced separately for both the Endek Stream Basin and the Kırmızı Stream Basin.

According to the analysis results, in the Endek Stream Basin, the discharge reached its peak approximately 18.5 hours after the onset of precipitation, with a discharge volume of 14,408.3 $m^3/s$. In the Kırmızı Stream Basin, the peak occurred approximately 2.5 hours after the precipitation began, with a discharge volume of 4,251.3 $m^3/s$. To assess the model's accuracy, reports of the July 2010 flood disaster in Saçlık Village, which resulted in six fatalities, were examined. These examinations revealed that the model yielded highly consistent results in terms of timing and magnitude.

Thus, it has been observed that such a study is beneficial in predicting the potential effects of flood disasters, particularly in terms of discharge magnitude and flow duration, and how the disaster might impact the study area. Consequently, it is anticipated that this research will assist authorities in formulating disaster management strategies.

However, more accurate and detailed results require the use of higher resolution data and advanced modeling techniques.

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# INTRODUCTION

Floods, observable in almost every region including the driest climates, are defined as "the uncontrolled flow and spread of large water masses in river beds, valley slopes and floors, depressions, and coastal areas due to various reasons" (Özcan, 2006). When floodwaters spread to villages, cities, towns, fields, or gardens, they cause inundations, transforming this natural event into a disaster (Sanır, 2000).

Floods can occur due to the influence of multiple factors. Among these, meteorological factors include heavy rainfall, snowmelt, wind, and storms. Topographic factors involve landforms (such as valley floors), steep slopes, and river or streambeds, especially those that have been subject to human interventions like the construction of bridges, roads, and dams. Human factors consist of urbanization, deforestation, and inadequate infrastructure. Additionally, soil composition (particularly clayey soils) and hydrological factors like high groundwater levels and the uncontrolled release of water from dams and levees are some of the most impactful contributors to floods.

In recent years, especially with the effects of climate change and increasing human activities, the frequency and intensity of natural disasters have risen. Floods have caused significant loss of life and property in both the world and Turkey in recent years. For instance, in 2023 alone, preliminary reports indicate that 499 people died in Peru, 4,300 in Libya, 438 in the Democratic Republic of Congo, 17 in Greece, 537 in Malawi, and 215 in Pakistan. Moreover, in countries such as China, India, Bangladesh, Myanmar, Somalia, and Libya, thousands of people lost their lives, and millions were forced to abandon their homes (Anadolu Haber Ajansı, 2023).

According to AFAD statistics, a total of 346 flood events occurred in Turkey in 2023 alone. When examining significant flood events between 1950 and 2018, a total of 6351 records were reached. Accordingly, the provinces with the highest number of floods are Erzurum (425), Sivas (315), Van (265), Bitlis (247), and Kayseri (211), respectively (AFAD, Türkiye'de Afet Yönetimi ve Doğa Kaynaklı Afet İstatistikleri, 2018).

Climate change and increasing human activities are amplifying the frequency and intensity of natural disasters. Floods, in particular, pose significant threats to both local governments and residents. In this context, hydrological modeling and predictions are crucial for developing disaster management and risk reduction strategies. This study aims to determine the potential destructive effects of sudden rainfall events in the Horasan district of Erzurum using hydrological data and unit hydrographs.

One of the most important stages of flood prevention measures is to determine the potential flood hazard. Numerous analytical methods have been developed for this purpose (Esri Documentation, 2024). In this study, unit hydrographs will be created for the sections of the Aras River Basin passing through the Horasan district. The goal is to estimate the magnitude of potential flood hazards by generating line graphs that illustrate how much water the river will discharge during a flood event.

This approach allows for a comprehensive analysis of flood risks in the region, taking into account both geographical features and hydrological data. By creating unit hydrographs, we can visualize and quantify the potential impact of sudden rainfall events, providing valuable information for local authorities and residents to develop effective flood management strategies.

Assumptions Used in Velocity Field Calculation;

1. Spatially Variable: The velocity of water varies according to location within the watershed. In other words, different water flow velocities are observed at different points in the watershed.

Factors such as topography (slope, flow accumulation), land cover (vegetation, soil type), and human interventions (dams, bridges) affect water velocity. These factors also vary spatially within the watershed. Example: Water velocity will be higher on a steep slope compared to a flat area. Similarly, water velocity will be lower in a forested area compared to bare land.

2. Time-Independent**:** The velocity of water at a specific point remains constant over time and does not change in response to rainfall events.

This assumption is typically used in unit hydrograph methods that assess short-term rainfall events and flash flood risk. During short-term rainfall events, although changes in water levels may be rapid, the velocity at which water passes a particular point may not significantly change in the short term.

This assumption may lose validity in long-term rainfall events and in rivers with continuous flow. This is because, in the long term, factors such as soil saturation, evapotranspiration, and snowmelt can affect water velocity.

3. Discharge-Independent: The velocity of water at a specific point is independent of the discharge amount. In other words, regardless of how much water flows in the river, the velocity at which water passes a particular point remains the same.

This assumption is used to make simplified hydraulic calculations. In reality, as discharge increases, water velocity also increases. However, this rate of increase may vary depending on factors such as river bed geometry and roughness.

Previous studies conducted in the Stowe region (Stowe is located in the state of Vermont, United States, and situated within Lamoille County) established flow direction and flow time layers and determined unit hydrograph coordinates (Esri Documentation, 2024). These methodologies will be adapted to the Horasan district. The data obtained will enable local administration and emergency authorities to plan and respond more effectively.

In line with the relevant international literature, various methods and approaches have been developed in studies where watershed delineation and hydrological modeling are critical. Particularly, the study conducted by Yen & Chow (1989) highlighted that determining flow accumulation and flow direction are fundamental elements for hydrological modeling. Additionally, research by McCuen (1998) introduced different methods used in hydrological analyses by focusing on rainfall-runoff models.

Researchers have made significant strides in predicting flood characteristics, particularly in terms of magnitude and duration, through the development of unit hydrographs. Several scholars have contributed to this field, each offering unique approaches to flood hydrograph prediction using unit hydrograph models. Notable works include those by Tarboton (1997), Clark and colleagues (2008), Chen and Hill (2007), and Kirkby (1976). These studies have collectively advanced our understanding of flood behavior and improved prediction methods. Additionally, the field has benefited from the valuable contributions of Singh (2003) and Beven (1982), who focused on kinematic wave modeling and surface runoff analysis, respectively. Their work has further enhanced our ability to understand and predict flood events, complementing the unit hydrograph approach with additional analytical techniques.

Furthermore, numerous flood risk analyses using unit hydrographs and different methods can be found in the local literature. For example, Benli & Özçelik (2020) conducted flood risk analysis using unit hydrographs in Bodrum, Daran (2023) in Defne, Gülbaz,(2019) in Istanbul, and Çanta, E.E. (2022) in Artvin. Additionally, many studies in the literature, such as those by Taş & Yanık (2022), Çorapçı & Özdemir, (2024), Özdemir & Akbas (2023),Özşahin (2013), Şenol (2019), Sarıgül & Turoğlu (2020), Sunkar & Tonbul (2011), Kesik, Aydınoğlu & Taştan (2016), Polat, Kopar & Yalçın (2023), Avcı & Sunkar (2015), Zeybek (2011), Kopar, Polat, Hadimli, & Özdemir (2005), Kumanlıoğlu & Ersoy (2018), Demir & Keskin (2022), Korkmaz (2022), and İstanbulluoğlu, Bağdatlı & Arslan (Şenol, 2019)(2017), have been utilized.

## STUDY AREA

This study aims to examine the hydrological characteristics of the Endek Basin and its tributary, the Kırmızı Dere Basin, located in the Horasan district of Erzurum. It also aims to provide guiding data on the estimation of discharge at the basin outlets and to suggest measures to be taken against flood events. Using isochron zones, the water drainage area in square meters was calculated, and unit hydrographs were determined. Subsequently, a unit hydrograph graph was created to show the times when discharge at the outlet was at its highest during a hypothetical rainfall event. Saçlık Neighborhood, situated upstream of the Endek River, is located at the confluence of the Kırmızı and Deli Streams (Figure 1), rendering it one of the most vulnerable locations within the basin to flood hazards due to the terrain's (Figure 2).

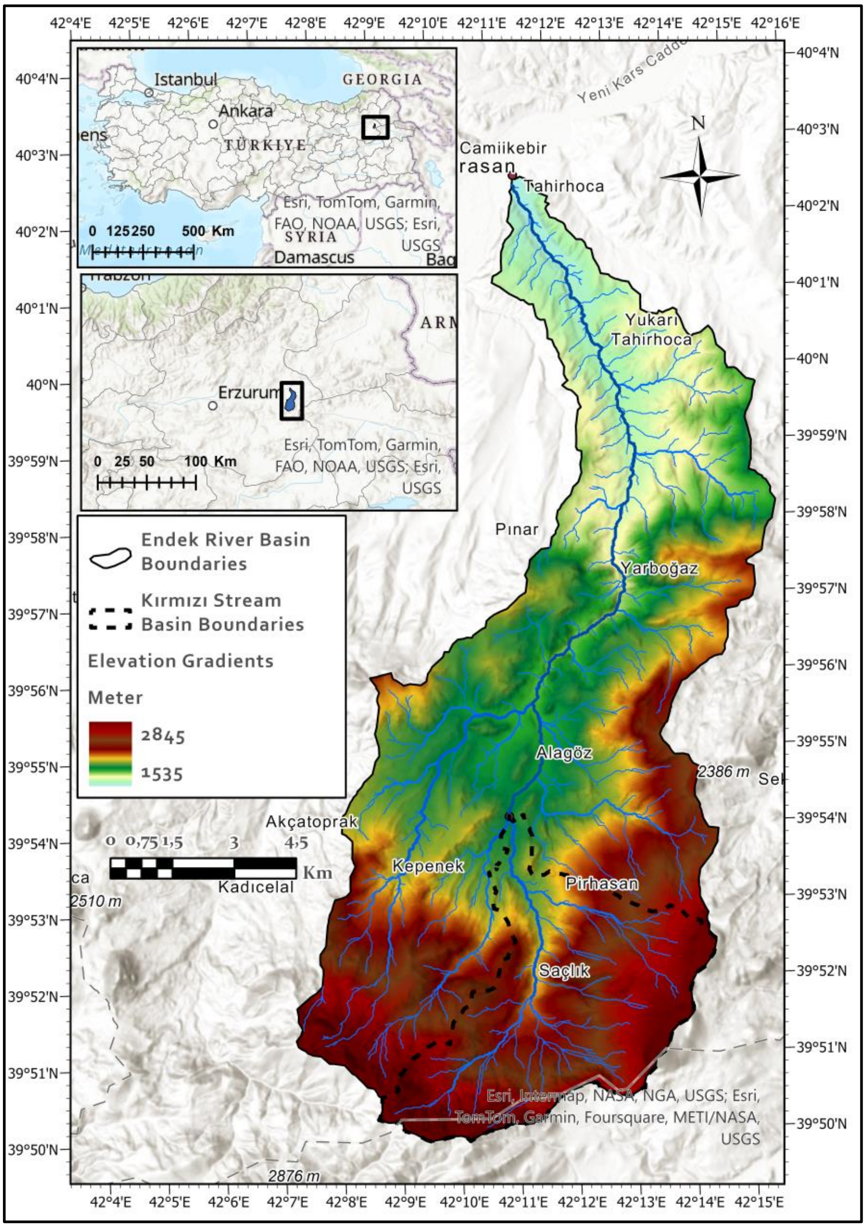


**Figure 1:** Location Map of the Endek Stream and Kırmızı Creek Basin (Erzurum/Horosan/Turkiye).

These waterways, incorporating numerous tributaries in their middle reaches, traverse through neighborhoods such as Alagöz, Yarboğaz, Yukarı and Aşağı Tahirhoca, posing significant threats, especially during the spring and summer months.

The Horasan district of Erzurum is characterized by a continental climate and irregular precipitation patterns. Such conditions increase the risk of floods and pose a danger to the local population. According to AFAD (2018) statistics, Erzurum province has experienced the highest number of flood incidents among Turkish provinces, with 425 occurrences between January 1, 1950, and June 1, 2018 (AFAD, 2021). Additionally, the AFAD Erzurum IRAP (2021) report indicates that there have been five significant flood disasters in the Horasan district over the past 25 years. The most notable of these occurred in July 2010 in the village of Saçlık (located in the Kırmızı Dere Basin, a tributary of the Endek Basin), where the Kocabaş family's home was swept away by floodwaters, resulting in the loss of six lives (CNNTÜRK, 2024; AFAD, AFAD IRAP, 2021). The location of the flood event was in the center of Saçlık Village, where the Kırmızı Stream and Deli Stream converge. The location of the flood event was in the center of Saçlık Village, at the confluence of the Kırmızı Stream and Deli Stream. Today, this area is largely abandoned as most of the houses have been moved (Figure 3). Such tragic events underscore the importance of hydrological studies in the region.

**Figure 2:** The southern part of the Kırmızı Dere where it joins with seasonal streams.

**Figure 3:** The Saçlık Village Center, where the flood occurred.

# MATERIALS AND METHODS

This study utilized hydrological data from the Erzurum Horasan region. The data was prepared as an ArcGIS Pro project, with methods applied sequentially.

Flow direction is a critical component of hydrological modeling. We generated the flow direction layer using 25-meter resolution Corine Erzurum DEM data (Copernicus, 2024). As this layer encompassed areas beyond the outlet basin, we created a basin-specific flow direction layer. To determine flow duration, we employed both flow direction and weight layers. The weight represents water impedance across the terrain, varying according to land types such as forested areas or flat rock surfaces.

We analyzed the unit hydrograph coordinate, U, over specific time intervals between i and t (where i = 1, 2, ..., n). The equation used to determine flow length is as follows:

$$U_i = U(i\Delta t) = \frac{A(i\Delta t) - A\big((i-1)\Delta t\big)}{\Delta t}$$

(Esri Documentation, 2024).

$U_i$ is the unit hydrograph ordinate at time $i$,

$i\Delta t$ represents the time step,

$A(i\Delta t)$ is the cumulative area contributing to runoff at time $i$,

$A\big((i-1)\Delta t\big)$ is the cumulative area contributing to runoff at the previous time step $(i-1)$

$\Delta t$ s the time increment.

This formula calculates the unit hydrograph ordinate at time "$i$" by taking the difference in cumulative areas between two consecutive time steps, divided by the time interval "$\Delta t$". It is used in the construction of a unit hydrograph to represent the flow response of a watershed to a unit volume of rainfall excess.

In this study, a more detailed time frame was used to estimate the water volume reaching the outlet point per second. This approach allows for more precise flood predictions and intervention planning.

Based on the obtained data, a unit hydrograph was created showing peak water discharge times at the outlet point during predicted rainfall events. This data was analyzed in a GIS environment, with maps used to visualize and interpret the findings.

Throughout the study, was utilized ArcGIS Pro software and various ArcGIS tools. These tools were employed in different stages, including flow direction determination, weight calculation, and unit hydrograph production. Detailed information about these tools has been provided in the findings section.

An in-depth analysis of the region's hydrological characteristics was conducted through this comprehensive approach, considering both geographical features and temporal factors affecting water flow. The accuracy of the model was enhanced using high-resolution DEM data and the creation of basin-specific layers, providing valuable insights into the area's hydrological behavior.

To create unit hydrographs for the Endek Basin and its sub-basin, Kırmızı Dere in Horasan, a water flow basin was first developed using ArcMap software. The time required for water to reach the stream outlet point was then calculated. This allowed for the estimation of how quickly a hypothetical extreme rainfall event could cause flooding in the basin. The time taken for water to flow to a specific location was determined using various mathematical formulas implemented in GIS software. Created a velocity field that varies spatially but remains constant over time and discharge. This velocity field assumes:

1. Velocity is influenced by spatial components such as slope and flow accumulation (spatially variable).
2. Velocity at a specific location doesn't change over time (time-invariant).
3. Velocity at a given location is independent of water flow rate (discharge-invariant) (Esri Documentation, 2024).

In reality, velocity and time can be variable, and discharge is certainly variable. However, achieving 100% accuracy and precision with the available data and current technology is impossible. Therefore, an analysis was conducted using various geomorphological and hydrographic data obtained from the terrain model, considering observable land characteristics. The basin boundaries were first defined in ArcMap by setting a pour point and using the Watershed tool to delineate the main basin and sub-basins. Flow accumulation and flow direction were then determined using tools from the Hydrology toolset. Percent slope groups were also created for use in the analyses (Figure 4d), which were derived from 25-meter resolution DEM data (Copernicus, 2024).

After processing all this data, a raster velocity layer for the study area was created, which is spatially variable but invariant with time and discharge. This process was applied to both the main basin (Endek Stream) and the sub-basin (Kırmızı Dere). Following the acquisition of basic data, the following steps were performed:

**Calculation of the Velocity Field;** To determine the velocity field, we first needed to calculate the slope-area term. After preparing raster layers for both slope and flow accumulation areas, we combined them to create a new raster layer representing the slope-area term (Figure 4a, 4b, 4c, 4d and 5a). To calculate the velocity field, we needed to compute the slope-area unit, expressed as "$s^b A^c$" in the formula proposed by Maidment et al. (1996).

The Raster Calculator tool in ArcGIS Pro was used, and the following formula was entered in the Map Algebra expression section:

$$\text{SquareRoot("Endek\_havzasi\_slope")} \times \text{SquareRoot("Endek\_havzasi\_flow\_accumulation")}$$

The square root of both slope and flow accumulation was used because the coefficients (b = c = 0.5) suggested by Maidment and colleagues were adopted. The coefficient '0.5' is equivalent to the square root of the value.

Having determined the average slope-area term across the basin, which is a crucial component of the velocity field equation, the calculation of the velocity field could proceed. In this method, introduced by Maidment et al. (1996), a velocity is assigned to each cell in the velocity field based on its slope value and the area contributing to upstream flow (i.e., the number of cells flowing into it or flow accumulation). The following equation is used:

$$V = V_m \times \frac{s^b A^c}{s^b A_m^c}$$

Here, "V" represents the velocity of a single cell with slope "s" and upstream contributing area "A". The coefficients "b" and "c" can be determined through calibration, a statistical method for adjusting model parameters to align estimated data closely with observed data. In this scenario, was used the recommended values of "$b = c = 0.5$". "$V_m$" is the average velocity of all cells in the basin, assumed to be 0.1 m/s. Lastly, "$s^b A_m^c$" is the average slope-area term across the watershed. To avoid unrealistic fast or slow results, velocity limits were set: a minimum of 0.02 m/s and a maximum of 2 m/s (Figure 5).

To implement this, we first created an unlimited flow velocity file using the mean value from the statistics section of our slope-area term file. The ArcGIS Pro Raster Calculator tool was used with the following formula:

$$0.1 \times \left(\frac{\text{Stowe\_slope\_area\_term}}{\text{[Mean slope-area term]}}\right)$$

For the Endek Stream Basin, the value was found to be "14.33603924607821". Limits were then applied to this unlimited velocity file using the Con tool in ArcGIS Pro, with a lower limit set to 0.02 m/s and an upper limit set to 2 m/s (Figure 5b). This process resulted in the Endek Basin flow velocity map (Endek Basin Velocity), (Figure 5c).

**Reclassification of Flow Time Based on Isochrone Zones;** Flow time is calculated using a relatively simple equation: the length of time water needs to flow is divided by its velocity. While the velocity field indicates how fast water flows, the flow time still needs to be determined. To do this, two variables are required: flow direction and weight. The flow direction has already been established. The weight term represents impedance. For instance, water flowing through forested terrain takes longer than water flowing over flat rock due to terrain obstruction. Although calculating weight without detailed terrain data may seem challenging, a more generalized equation can be derived based on the following two equations to find flow time:

$$T = \frac{L}{V}$$

$$T = L \times W$$

Where:

- T is the flow time,
- L is the flow length,
- V is the velocity, and
- W is the weight (impedance).

By combining these two equations, we can derive the following formula for weight:

$$W = \frac{1}{V}$$

(Maidment, 1996; Clark, C. O., 1945; Esri Documentation, 2024).

To apply this formula in ArcGIS Pro, we used the Raster Calculator tool, entering it as:

$$\frac{1}{\text{“Endek\_havzasi\_velocity”}}$$

The resulting map was named “Endek_havzasi_watershed_flow_direction”. This file was then used to calculate the flow length parameter using the Flow Length tool. While this tool normally calculates flow length, it has an optional parameter to include a weight raster. When a weight raster is included, the tool calculates flow time instead (Esri Documentation, 2024). To achieve this, the Endek Basin flow direction and Endek Basin weight files were input into the Flow Length tool, and ‘downstream’ was selected in the direction of measurement section. This process yielded the flow time raster (Figure 6).

In this raster layer, each cell contains a value representing the time, in seconds, it takes for water to flow from that cell to the outlet. Darker colors indicate shorter flow times. Water flowing through low-lying stream beds closest to the outlet takes the least time, while water from areas farther from the outlet takes longer (Esri Documentation, 2024).

After all raster files were prepared, various calculations were performed, and tables were created using the obtained information. To construct the unit hydrograph table, the total pixel count of each isochrone area was first multiplied by the resolution of the DEM data used in the study (25m x 25m) to calculate the area.

**Preparation of the unit hydrograph table;** We then created a graph showing time on one axis and drainage area on the other, illustrating how much water reaches the outlet over 1,800-second (or 30-minute) intervals (Table 1). We chose this time frame based on the assumption that in a hypothetical flash flood emergency, a 30-minute period could mean the difference between life and death. However, this time interval can be adjusted for different scenarios.

## FINDINGS

Through this process, a velocity field that varies spatially but remains constant over time and discharge was generated, using flow accumulation and slope raster layers. One of many formulas capable of calculating velocity fields was employed to achieve this. Now that the speed at which water flows through the Endek Stream Basin during a hypothetical sudden rainfall event is understood, the time it takes for water to reach the outlet can be determined.

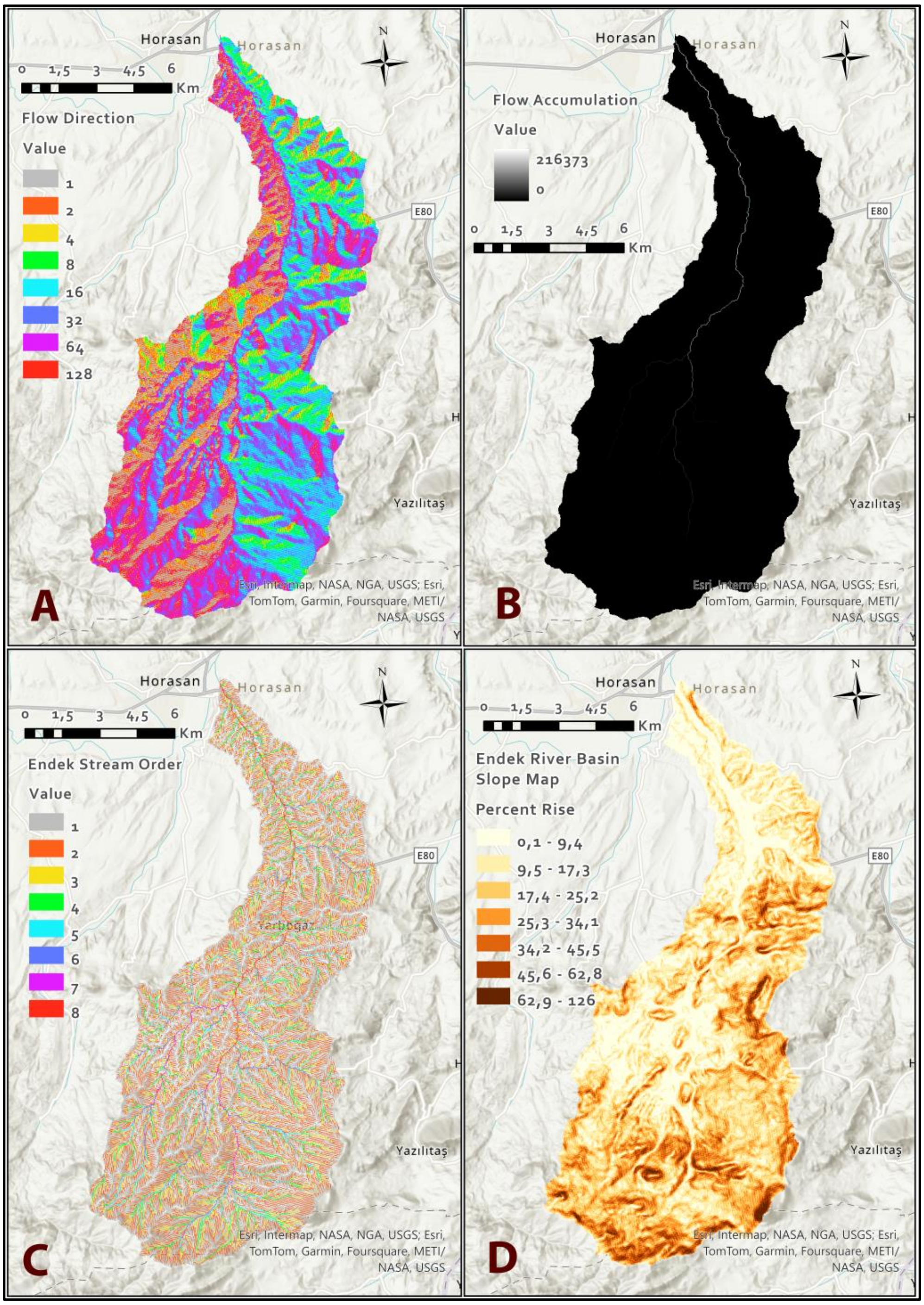


**Figure 4:** Hydrological Analysis and Slope Mapping of the Endek River Basin: A) Flow Direction, B) Flow Accumulation, C) Stream Order, D) Slope Map.

While the velocity field indicates that water moves fastest along the streams passing through villages, this alone is insufficient for creating a unit hydrograph. Information on the time required for water to overflow to the outlet point is still lacking. To address this, an isochrone map illustrating the time it takes for water to travel from any point in the area to a specific location needs to be created. As a preliminary step in developing this isochrone map, a weight grid (Endek Basin Weight) was created, as shown in Figure 5d.

On this map, darker colors represent slower velocities, while lighter colors indicate faster velocities. Water tends to flow fastest where the largest amount of water accumulates (Esri Documentation, 2024). This approach provides a comprehensive visualization of water flow velocities across the Endek Basin, crucial for understanding its hydrological behavior and potential flood risks.

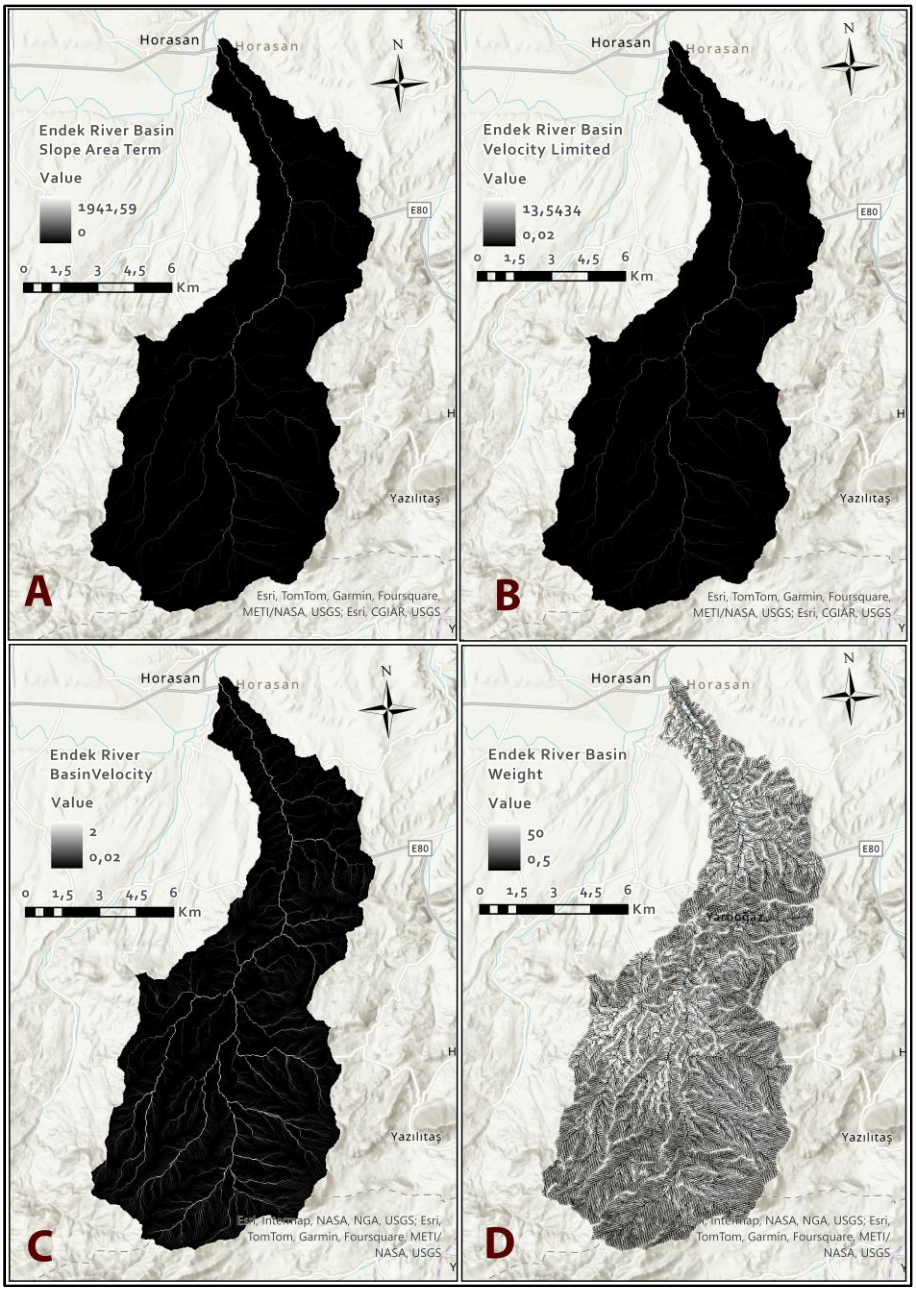


**Figure 5:** Maps Utilized in the Velocity Field Calculation of the Endek River Basin. A) Slope Area Term Map, B) Velocity Limited Map, C)Velocity Map D)Weight Map.

This approach allows for the visualization not only of the speed of water flow but also of the time it takes for water to reach critical points within the basin. The weight grid serves as a foundation for the isochrone map, considering factors that may impede or accelerate water flow across different areas of the basin. By combining this with velocity field data, a comprehensive model of water movement during flood events can be created, which is crucial for effective flood risk management and response planning in the Endek Stream Basin.

Finally, we reclassified this flow time raster according to isochrone regions. An isochrone is a contour line passing through points with roughly equal travel times to the basin outlet. We defined isochrones at equal time intervals of 1,800 seconds (or 30 minutes). While different intervals could be used for larger areas, this time frame was deemed suitable for the Endek Stream and Kırmızı Dere watersheds. In this scheme, cells in the first isochrone region take approximately 1800 seconds to reach the outlet, those in the second region take about 3600 seconds, and so on, up to the highest value in the Endek Basin Time dataset of 78,325.5 seconds (figüre 6). We segmented these times into intervals (e.g., 0 to 1,800 or 1,800 to 3,600 seconds).

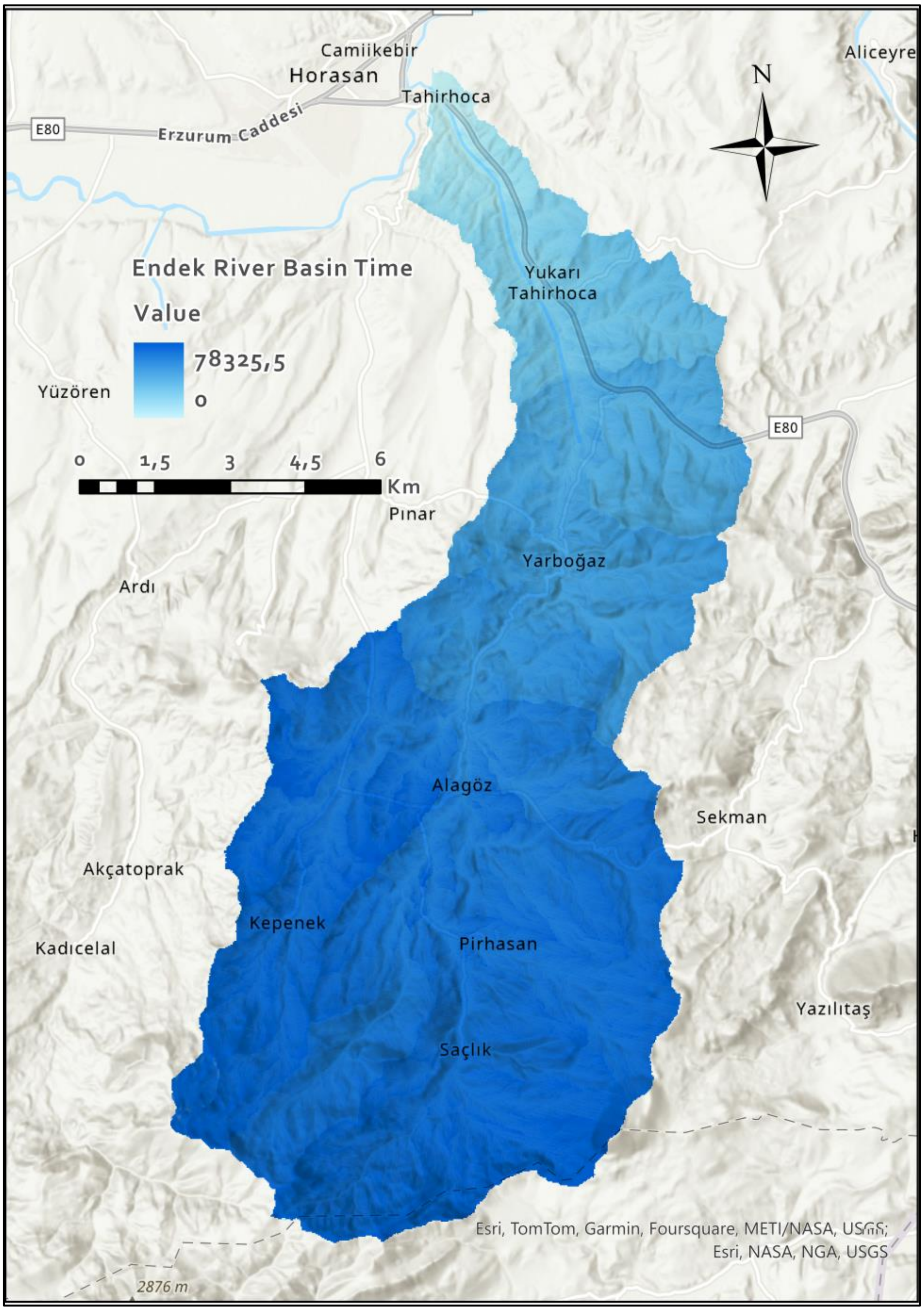


**Figure 6:** Endek River Basin Water Travel Time Map.

To accomplish this, we used the Reclassify tool in ArcGIS Pro, resulting in the creation of an isochrone map (Figure 7). These time intervals will serve as ordinates in the unit hydrograph graph. This approach allows us to visualize and quantify the time it takes for water to travel from different parts of the basin to the outlet. The isochrone map provides crucial information for understanding the basin's hydrological behavior, which is essential for flood risk assessment and management. By breaking down the basin into these time-based regions, we can more accurately predict how quickly a flood event might develop and where the most critical areas for intervention might be.

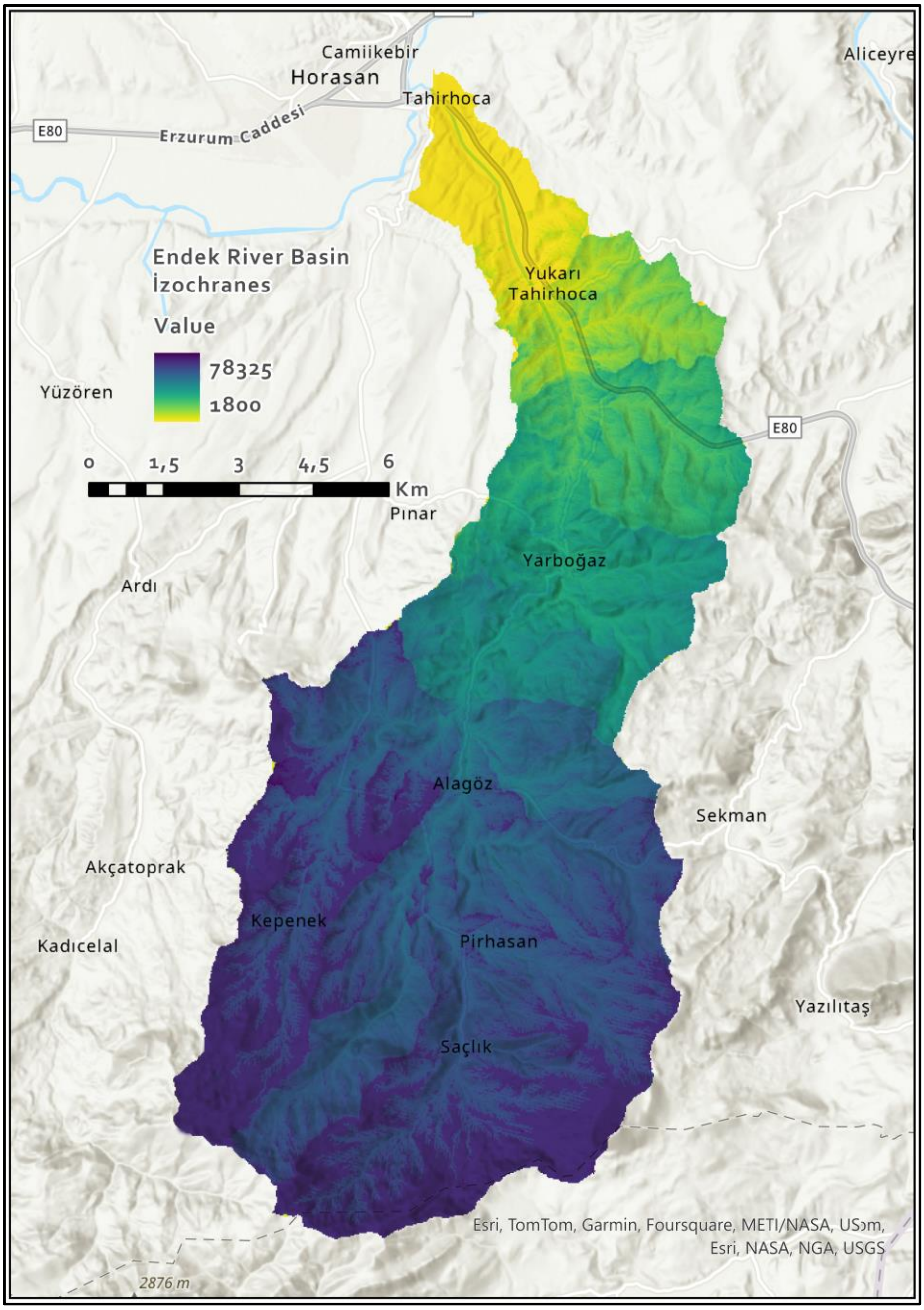


**Figure 7:** Endek River Basin Izochranes Map.

Examining the flood graph for the Endek Stream Basin reveals peak discharge values occurring at different times in various parts of the basin. Approximately one hour after the onset of sudden rainfall, the discharge reached 517,7 m²/s. This value is typically observed in areas close to the basin's outlet (Horasan Center and Tahirhoca District). Subsequently, peak points were reached at different locations after 4 hours (392 m²/s), 6.5 hours (606,6 m²/s), 9 hours (1237.2 m²/s), 11 hours (2124 m²/s), and 13 hours (2354 m²/s). The largest flow in the basin was calculated to occur approximately 18.5 hours after the start of rainfall, reaching 14,408.3 m²/s (Figures 7 and 8).

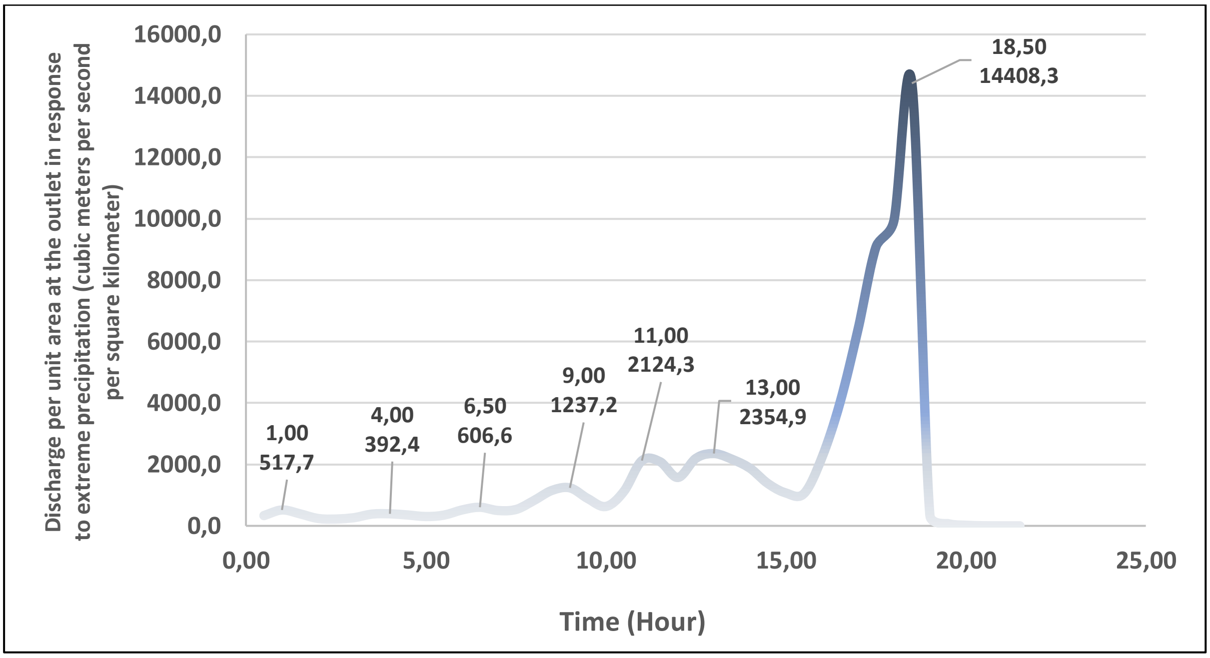


**Figure 8:** Unit hydrograph flood diagram at the outlet of the Endek Stream Basin.

Given that this flood analysis was conducted on a considerably large basin, the resulting outcome will have a rather general value. Furthermore, as it's highly unlikely for a flood event to occur simultaneously in all sub-basins of such a large area, verifying and validating the data becomes challenging. To address this, we applied the same procedures to create a unit hydrograph graph for the Kırmızı Dere Basin, a tributary of the Endek Stream Basin (Figure 9).

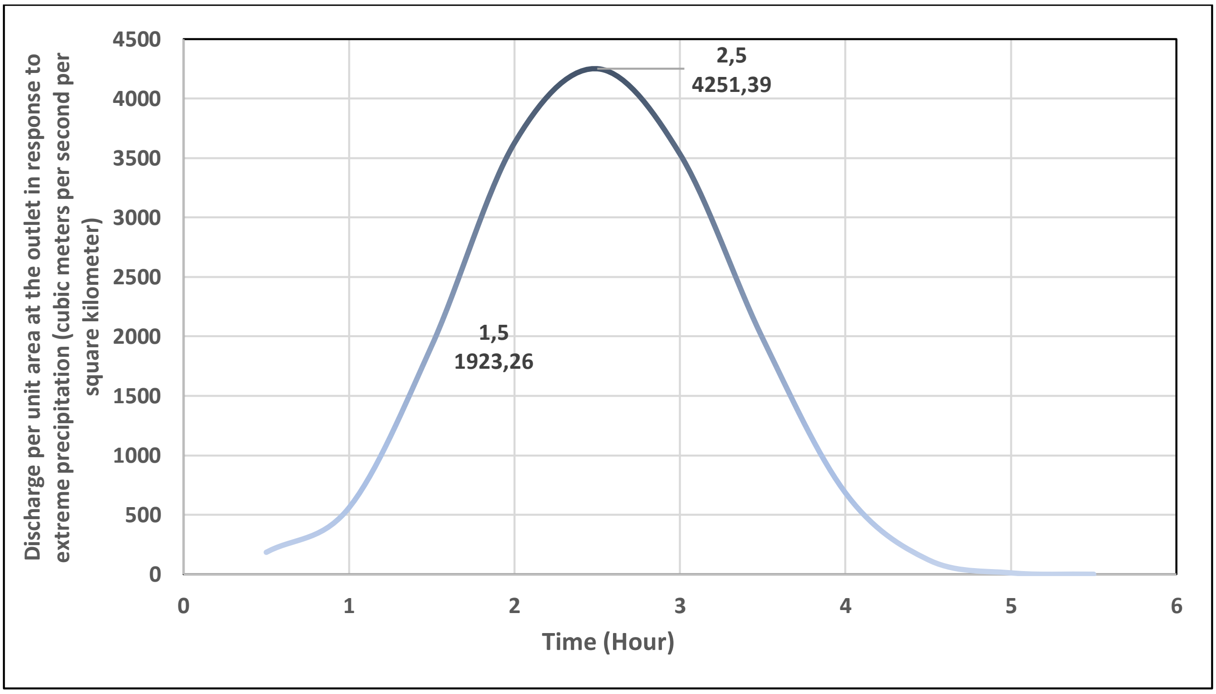


**Figure 9:** Unit hydrograph flood diagram at the outlet of the Kırmızı Creek Basin.

The focus on this particular basin stems from the flood disaster that occurred in Saçlık village, as mentioned in the introduction. This flood event was the most severe disaster in the region in recent years. Examining reports of the July 2010 flood, which claimed six lives, reveals that excessive rain and hail, combined with the lithological structure and slope, had a rapid impact. The rainfall reportedly began around 14:00 and the flood affected the village by 14:40 (AFAD Provincial Disaster Risk Reduction Plan, 2021; Yeniasya, 2024). These data closely align with the values in the unit hydrograph flood graph and Kırmızı Dere Basin isochrone maps prepared in ArcGIS Pro (Figures 9 and 10).

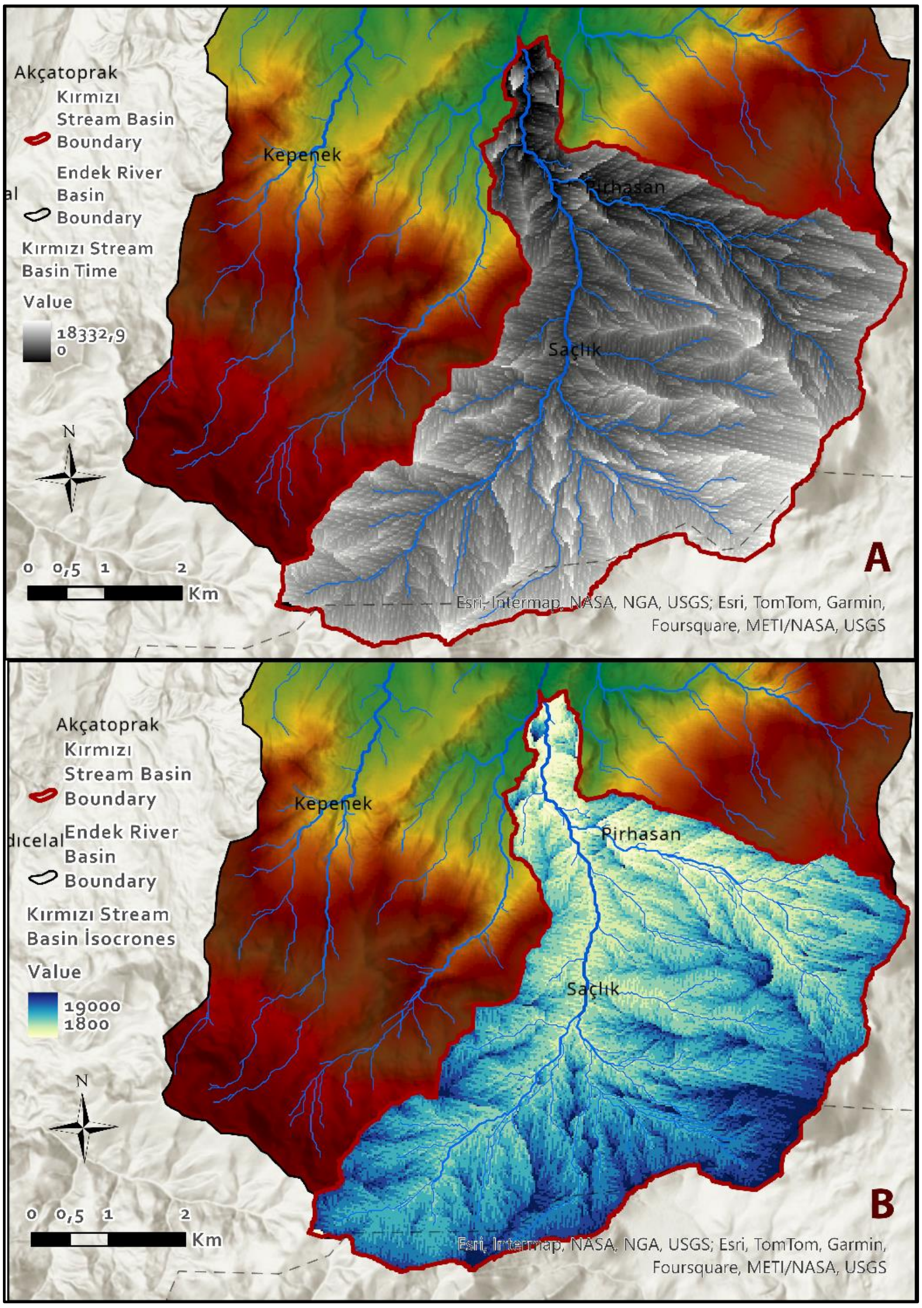


**Figure 10:** Kırmızı Stream Basin Water Travel Time and Isocranes Map.

Indeed, the analysis shows that approximately 2.5 hours after the onset of sudden rainfall in the Kırmızı Dere Basin, the stream discharge peaked at 4251.3 m²/s. In Saçlık Village and its immediate vicinity, where the flood occurred, the approximate value was 1923.2 m²/s after about 1.5 hours. It's important to note that this analysis was conducted considering a flood mass of up to 2 meters. The actual flood in the village did not reach such high values, which, when taken into account, demonstrates the consistency of the simulation.

After the flood disaster in Saçlık village, numerous preventive measures were undertaken, particularly the relocation of settlements established near the riverbed. In the lower areas, such as the settlements of Alagöz, Yarboğaz, and Tahirhoca, river rehabilitation efforts were carried out, including the construction of retaining walls and various reinforcements in areas where the rivers pass through the settlements (Figure 11).

**Figure 11:** River retaining walls and streambed rehabilitation in Alagöz village.

However, despite all these regulations, the riverbed is being filled uncontrollably with various wastes by the villagers (Figure 12). Such practices will obstruct water flow during sudden rainfall and lead to water accumulation. Therefore, it is essential to educate the local population on this matter and enforce punitive measures for such actions.

**Figure 12:** The uncontrolled filling of the riverbed with waste materials.

## DISCUSSION AND CONCLUSION

Unit hydrograph analyses were conducted for the Endek Basin and its sub-basin, Kırmızı Dere, in Erzurum's Horasan district. Hydrographs and isochrone maps, providing valuable insights into the basins' hydrodynamic behavior, were generated using ArcGIS Pro software.

The unit hydrograph analyses conducted for the Endek and Kırmızı Stream Basins have made significant contributions to determining the potential flood risks in the region. Specifically, it was found that following rainfall, the Endek Stream reaches a peak discharge of 14,408.3 m³/s in approximately 18.5 hours. For Kırmızı Stream, this time was calculated as 2.5 hours, with an estimated peak discharge of 4,251.3 m³/s. These results provide critical insights for local authorities to develop effective flood management strategies.

When comparing the findings of this study with similar studies conducted in Turkey, it is observed that the results align with previous analyses in the literature. For instance, in a study conducted by Benli and Özçelik (2020) in Bodrum, flood risks in the region were analyzed using the unit hydrograph method. Similar variations in flow times and discharge magnitudes between basins were revealed in their findings, further demonstrating the effectiveness of unit hydrographs in flood risk analysis. The Bodrum study highlights the utility of unit hydrographs as a valuable tool for flood risk assessment.

In addition, when compared with similar international studies, the results of our study are consistent with other analyses in the literature. For example, the study conducted by Yi et al. (2024). in China found that the dynamic time-varying unit hydrograph model used across different watersheds was highly successful in predicting floods. This model was calculated based on saturated areas and demonstrated higher accuracy compared to traditional unit hydrograph methods.

This comparison reinforces that the unit hydrograph method is particularly effective in regions with saturated areas and limited data availability, confirming the validity of the method used in our study.

**Limitations:** This assumption may lose validity especially during extreme rainfall events and flood situations in river beds. This is because at high discharge values, water may overflow from the riverbed and exhibit different flow dynamics.

### Conclusion

These assumptions demonstrate that the unit hydrograph method is a simplified model. Therefore, model results may not fully reflect the complex hydrological processes in the real world. However, they can provide useful information, especially in applications such as flash flood risk assessment and development of early warning systems.

To improve the accuracy of the model, it is important to use higher resolution data, develop more complex hydrological models, and calibrate model parameters according to local conditions.

Considering past studies and analyses conducted in the Horasan district, it is understood that the flood risk is quite high and that more emphasis should be placed on hydrological studies in the region. The flood disaster that occurred in Saçlık Village has once again highlighted the vital importance of understanding the hydrological dynamics of the region more deeply and making accurate flood predictions.

The results of this study provide valuable insights into the prediction of flood disasters and the identification of potential hazards in advance. The findings align with the flood disaster that occurred. Accordingly, to minimize the impacts of a potential flood disaster in Saçlık Village and to ensure that the villagers are not affected by the flood, authorities need to intervene within a minimum of 30 to a maximum of 90 minutes. Isochrone maps and unit hydrographs can assist local authorities in developing intervention plans and implementing flood prevention strategies more effectively. Additionally, they form a crucial foundation for future studies.

This study provides valuable insights into assessing the potential flood magnitude in the Endek Creek Basin. However, it has several limitations that should be noted. The use of 25-meter resolution DEM data may not adequately represent some small-scale topographic features. The model employs simplified assumptions, such as considering the velocity field to be independent of time and discharge. Additionally, the study utilizes a hypothetical scenario rather than real-time precipitation and flow data. Furthermore, the research does not address the potential impacts of land use/land cover changes and climate change on flood risk. These limitations indicate that the results should be interpreted with caution and suggest that future studies should incorporate higher-resolution data, more complex hydrological models, and the integration of real-time data.

Following such identification studies in the basin, it is necessary to implement measures to prevent or mitigate the effects of flood disasters. In this regard:

- Creating dams and reservoirs to control floodwaters,

- Constructing flood barriers in riverbeds,

- Establishing effective drainage systems,

- Increasing green areas to ensure the natural absorption of water,

- Implementing early warning systems,

- Educating the local population about flood risks and necessary precautions,

- Ensuring controlled land use in accordance with land classifications,

- Utilizing remote sensing and GIS effectively to prepare up-to-date and detailed flood risk maps, modeling, and simulations by academics,

- Preserving natural waterways to prevent disruption of drainage by construction and infrastructure systems,

- Rehabilitating wetlands and marshes,

- Collecting more detailed hydrological and meteorological data,

- Providing legal regulations, financial support, and international cooperation to reduce flood risk and conduct post-flood relief efforts are some of the measures that should be taken.

In conclusion, this analysis of the Horasan region offers a new perspective for flood management and planning at local and regional scales. Future research can build upon these findings to conduct more comprehensive and detailed analyses, potentially helping to protect the local population from flood disasters.

This study contributes significantly to our understanding of flood dynamics in the Horasan region and provides a valuable framework for future hydrological research and flood management strategies in similar terrains.

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