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CIVIL ENGINEERING

Dam failure analysis according to different methods in HEC-RAS, Gökçe Dam, Turkey

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ABSTRACT. As in the rest of the world, the impact of climate change is clearly felt in Turkey, while the effects of global warming, drought and flood-induced disasters continue to increase day by day. At the same time, water consumption is crucial for the survival of people. Efficient water use and conservation, facilitated by water resources management, should be recognized as a pressing contemporary concern. Recently, floods that cause a great deal of damage have started to occur frequently in Turkey. A possible flood that may occur in the demolition of Gökçe Dam has been a matter of curiosity. This dam is the most important water source for Yalova province and has been in service for a long time. Therefore, the aim of this study is to examine the flood risk situations of settlements in case of a possible Gökçe Dam failure or basin flooding. Additionally, the study aims to estimate the damages that may occur in houses of flooded areas. Piping and overtopping methods were used in HEC-RAS program to create flood maps, and the Van Eck and Kok damage curves were used to assess the damages. While water level varies between 0-1 meters in the most affected buildings in the overtopping method, this level is 2-3 meters in the piping method. The damage to buildings with a water level of 4 meters and above is quite high in the piping method, and it has been observed that greater damage may occur for lower water levels in the overtopping method. The total damage and number of affected buildings are higher in the piping method. Accordingly, a possible Gökçe dam failure would cause significant losses in both methods, especially in the piping method.

Keywords: dam failure; depth damage curve; HEC-RAS; piping overtopping methods; yalova gökçe dam.

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Introduction

Dams, which constitute a vital part of human civilization, have been studied throughout history, especially with the rise and fall of societies that are highly dependent on irrigation. Dams that hold large volumes of water on rivers around the world have been and continue to be built for hydroelectric power generation, flood control, irrigation, water supply, navigation, recreation and many other purposes (Jansen, 1988). Although dams and reservoirs are used for many different purposes, the damage caused by a dam failure is greater than any other disaster. Dam failures can be attributed to either partial or catastrophic failures resulting from large floods that are released downstream uncontrollably (Fread, 1993). According to the International Commission on Large Dams, approximately one-third of dam failures are caused by overflows, another third by pipe failures, and the remaining third by failures or liquefaction, among other factors (Froehlich, 1995).

If dams are built without adequate and methodical preliminary studies, the risks can be irreparable. The most significant risks associated with dam failures are possible floods that can cause immense damage. Since the volume, flow and speed of the flood resulting from a dam failure can be high, the damage to both natural and artificial lands, as well as the downstream areas of the dam, can be extremely large. Thus, it is essential to conduct research on dam failure, including parameters, route and flood development, to ensure downstream safety management, particularly due to disruptions of residential areas upstream of dam rupture (Amini, Bahrami, & Miraki, 2021). The most basic task of dam rupture analyses is estimating and guiding the breach out hydrograph (Wu et al., 2011). Therefore, the flood hydrograph shape along the river and the affected length are two important issues in dam failure analysis (Wahl, 1998). Flood forecasting assists in the development of an emergency plan to ensure the safety of life and property against flood hazards (Mohamed, 2018). Hydraulic models are tools used to accurately predict dam failure flood waves and their propagation along the downstream valley (Wang et al., 2015; Sowiński, 2006). Flood-prone areas after dam failure can be identified using Hydraulic models, GIS and risk matrix, and maps, flood velocity and depth, which can be combined to determine which of these areas are at risk. (Pham et al., 2020; Rezaee, Mahmuee, & Khaksefidi, 2014).

In the event of a dam failure, if there is a large reservoir upstream, the downstream flood wave can be severe enough to cause erosion and/or structural destruction. This event is usually sudden and can turn into a disaster, resulting in many deaths. One of the biggest dam failure disasters in history was the failure of the 267 m high Vajont concrete arch dam in Venice, Italy, in 1963, where more than two thousand people died (Guney, Tayfur, Bombar, & Elci, 2014). After a long rain in 1982, the Tous rock fill dam in Spain collapsed and resulted in significant impacts to the surrounding villages and towns, covering an area of approximately 300 km^2. Although the height of the flood wave reached 7 m and 100,000 people were evacuated from the downstream region, eight people lost their lives and a total of 200,000 people were affected by the disaster (Alcrudo & Mulet 2007). In 2002, a study conducted in Turkey by the State Hydraulic Works (SHW-DSI) examined dams taller than 15 m and between 5-15 m in height, with reservoir volume greater than 3 hm^3. The study found that 42% of the losses that these dam types can cause in case of failure are at the highest risk level, while 43% of them present a significant risk level (Elçi, Tayfur, Haltas, & Kocaman, 2017).

The most common and longest-serving dams in the world are rockfill dams. (Zhang, Xu, & Jia, 2009). The failure of rockfill dams can result in overflow and piping washout. (Foster, Fell, & Spannagle, 2000; Richards & Reddy, 2007).

With flood overflow mapping, dam failures and the size of the flood wave downstream of the dam can be calculated with many different software and programs. In 1981, the Hydrological Engineering Center of the US Army Corps of Engineers developed the Hydrological Engineering Center - River Analysis System (HEC-RAS), which is one of the most widely used programs in this field of study. It has been developed for different calculations of continuous and unsteady flow based on one- and two-dimensional modeling of the water surface profile of open channels. In one-dimensional models, unsteady flow calculations are made with the help of 1D Saint Venant Equations at the channel sections. In the 2D HEC-RAS model, on the other hand, a 2D flow field is created by generating a computational Finite Element network that solves the flood map, 2D Sallow Water Equations (Saint Venant Equations) or 2D Diffusion Wave Equations on the river channel and floodplain. (US Army, 2017).

Many researchers have used HEC-RAS for dam failure problems because it can model complex flow issues effectively. Joshi and Shahapure (2017) used the 2D HEC-RAS modeling approach in their study, in which a set of calculations were made based on the Ujjani Dam under flood failure to identify flood-prone areas downstream of the dam. Albu, Enea, Iosub, and Breabăn (2020) used the 2D HEC-RAS model to assess the spatial risk following the theoretical breach of the Sulita Dam on the Romanian Sitna River. This model included stagnant water floods, hydro-morphometric parameter calculations (flow rates, flood times, depths, and velocity), and well as evaluations of the affected buildings and land. Gogoase Nistoran, Popovici, Savin, and Armaş (2016) analyzed the depth, velocity and travel time of a dam failure flood wave for Bicaz dam in Romania using HEC-RAS. Temiz et al. (2021) have evaluated the flood scenarios of Yalova province with their analysis in HEC-RAS and suggested solutions for possible risks. Doğan, Temiz, and Sümer (2023) used HEC-RAS while performing flood risk analysis for Kamara stream.

According to the well-documented records of dam failures and events published by ICOLD, there has been a rapid increase in the construction of large dams over the past century. While only around 5,000 dams were built all over the world until 1950, the number of large dams in the 20th century was approximately 45,000. While the dam failure rate was 2.2% before 1995, nowadays it is 0.5%, due to strict safety rules and regulations brought with new technologies and innovations developed in the fields of design and construction.

Although 77% of all dams in the world are filled dams, 64% of them are earthfill dams and 13% are rockfill dams, whereas the remaining 32% are concrete and other types of dams, as can be seen in Figure 1, (Adamo, Al-Ansari, Sissakian, Laue, & Knutsson, 2020).

Gökçe Dam is one of the important water resources of the Marmara region. This dam, built on Selman Stream between 1980-1989, is still in operation and is important in terms of meeting the drinking and industrial water needs of Yalova province (Damla, Temiz, & Keskin 2020). It has been stated that undesirable operational changes have been observed in the reservoir levels of the Gökçe Dam, which feeds the province of Yalova, due to the recent increase in the climate change and irregular precipitation regimes (Damla, Temiz, & Keskin, 2020). The aim of this study is to examine the adequacy of the Yalova Gökçe Dam for the region with an increasing population, and to reveal the water needs of the region for the coming periods. In addition, two stages were considered for the evaluation of the risks that may arise for the center of Yalova in case of a possible flood or dam failure, according to changing climatic conditions. In this context, all the data regarding the Yalova Gökçe Dam, Sellimandıra Stream feeding the dam and the dam basin were obtained from the General Directorate of Meteorology (MGM) and DSI. Moreover, we periodically checked the measurements of the data provided in the field. By using these measurements, water budget and dam failure models were established, which led to our findings that have been considered necessary within the scope of the study.

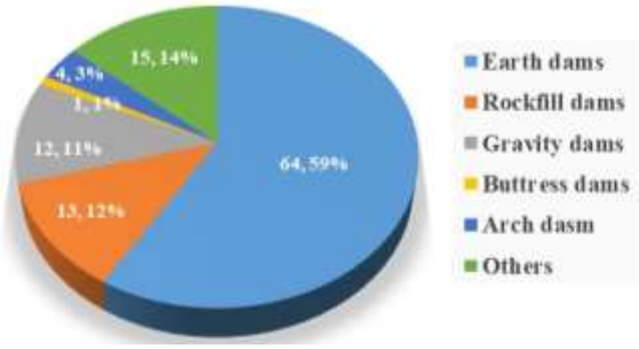


Figure 1. Percentage of all types of dams in the world, excluding China (Adamo et al., 2020).

In this study, damage calculations were made by examining the flood depth and the flood spread maps combined. For this reason, settlement areas and water depths in the study area were determined. The flood depth maps obtained as a result of the analysis performed in the HEC-RAS program and the water depths corresponding to the buildings were read. In order to find the damage ratio, we used the Van Eck and Kok (2001) method, which allows us to calculate the amount of damage according to the depth of water. Figure 2 presents the steps followed in this study.

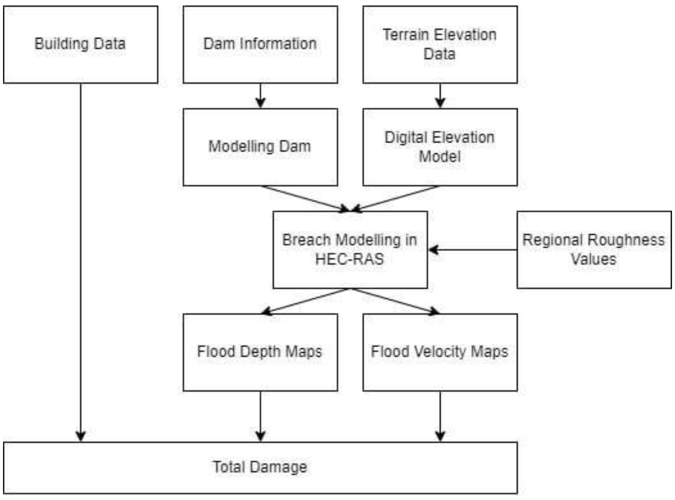


Figure 2. Flow chart of study.

Material and methods

Study Area

The area under study is the Gökçe Dam area, located between 28° 45' and 29° 35' East longitudes and 40° 28' and 40° 45' North latitudes, within the borders of Yalova province in Turkey. The Gökçe Dam is in the southwest of Yalova province and on the Yalova Thermal Road, its infill structure is of the rock body type, and it has a drainage area of 86.50 km^2. The distance of the dam axis to Yalova is 8 km, and the distance to Termal district is 3 km. In Figure 3, the general location of the dam basin is given, and Figure 4 presents the raste and tin data of the study area. The annual average flow is 69.24 hm^3/year, and the total water to be drawn from the dam is 43 hm^3/year. The Gökçe Dam is important for the primary water requirement of the Yalova region, in which is situated.

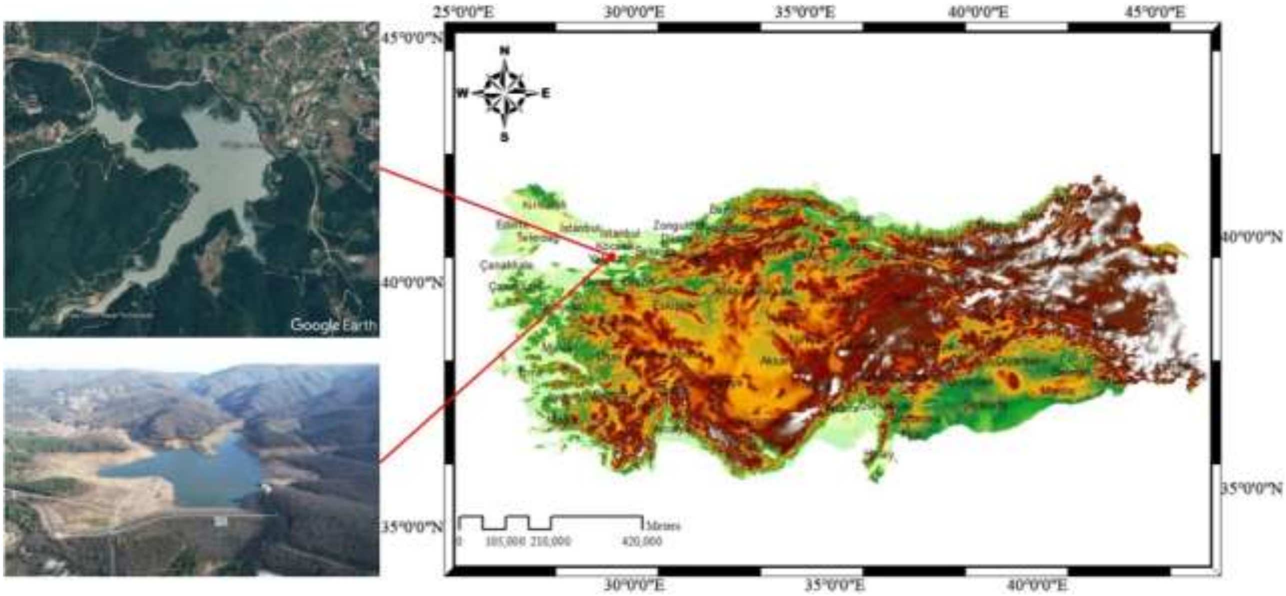


Figure 3. Gökce Dam location and satellite image.

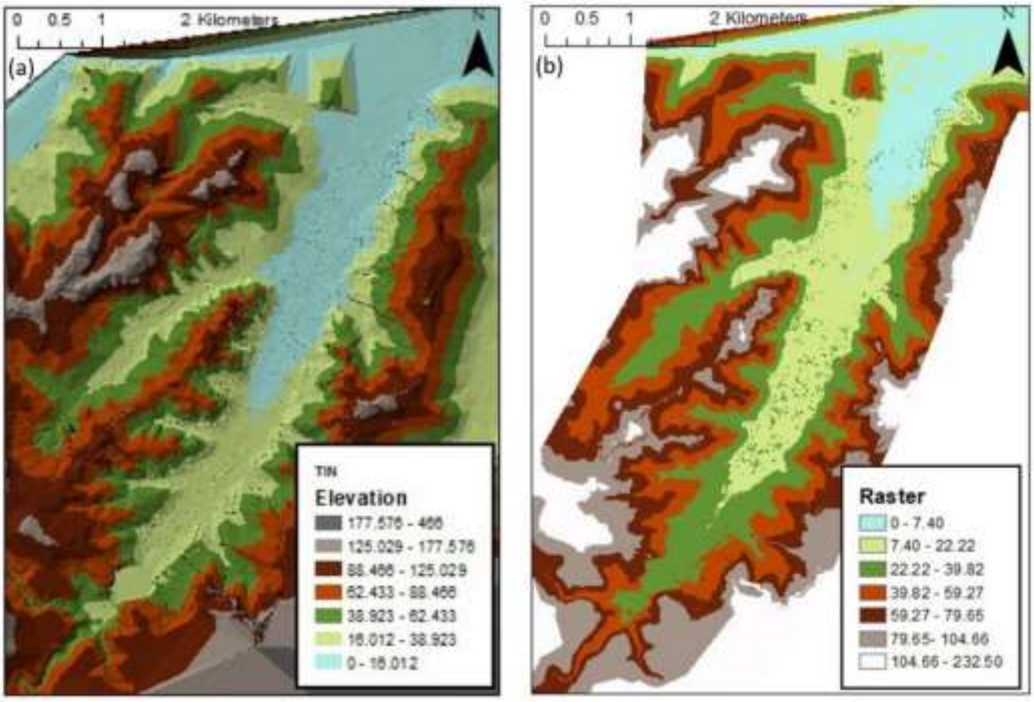
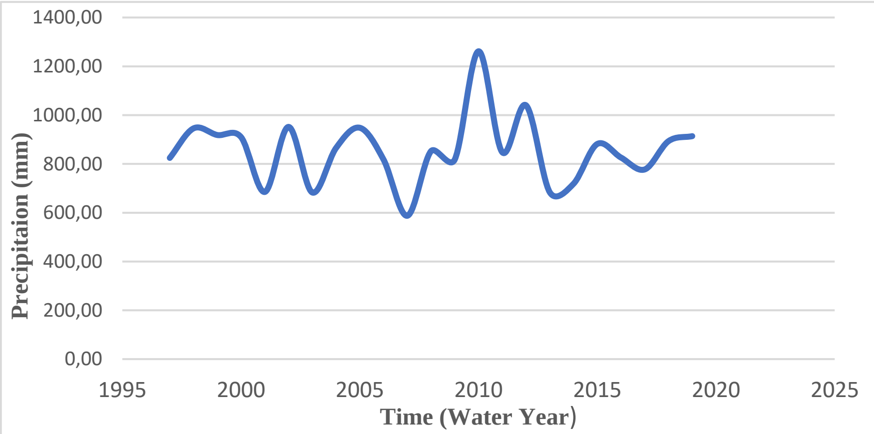


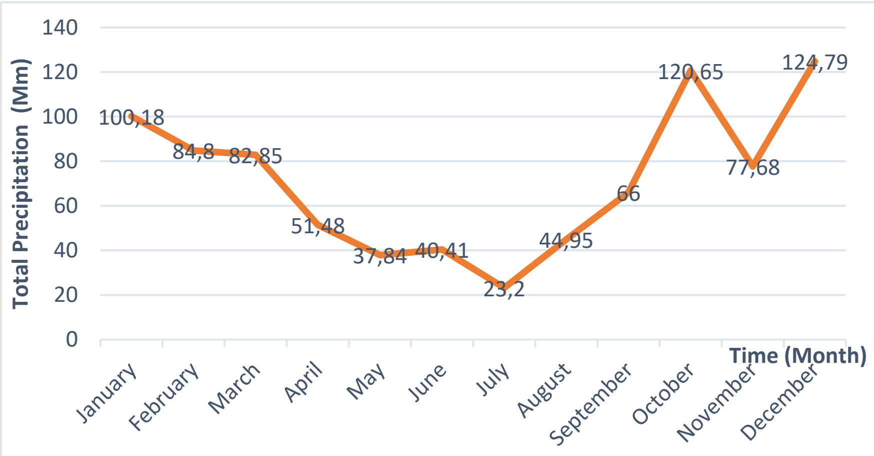
Figure 4. (a) Tin data (b) Raster data of study area.

Precipitation

The study area, Yalova Gökçe Dam Basin, has a moderately humid climate zone and the average annual precipitation varies between 600 and 1000 mm. The total annual precipitation graph of the basin area is shown in Figure 5a. Between 1997 and 2019, the average precipitation was 587.45 mm, and 2007 was the driest year. The highest precipitation was observed in 2010, with 1261.65 mm, which is well above the average year precipitation. The average annual precipitation was below 854.41 mm in the years of 1997, 2001, 2003, 2006, 2007, 2008, 2011, 2013, 2014 and 2017, as can be seen in Figure 5a. The total annual precipitation graph for Yalova Gökçe Dam between 1997 and 2019 shows a decreasing pattern. While the precipitation amount was 945 mm in the 1998 water year, this value decreased to 913 mm in 2019. Although there is an increase in certain years between 1997-2019 water years, a decreasing precipitation pattern can be observed. Figure 5b shows that, while the precipitation is very low during the summer months, it is higher in the months of December, January and February.



(a)



(b)

Figure 5. (a) Annual Total Precipitation (b) Average Monthly Precipitation.

GIS and HEC-RAS

Geographic information systems (GIS) are a set of systems established to load, store, query, calculate, manage and visualize all data according to geographic information. This system consists of maps, data, and the computer programs used to process the maps and data. With the help of GIS, all geographical or numerical information is visualized on various maps, so that many data sets can be seen and understood in a short time (Yomralıoğlu, 2000). GIS is used for mapping risks or current events, predicting events, managing, improving and modelling them with the help of various programs. These events may include flood (Celik, Aydin, Ozturk, & Dagci, 2006), drought, erosion (Yuksel, Gundogan, & Akay, 2008), natural events related to groundwater or surface water, as well as irrigation water and urbanization. These events can also comprise changes in land use (Atasoy, 2010), which includes artificial events that people do or plan to do, such as building a dam (Coskun et al., 2010), and their effects. As a result of the diversity of these events, GIS is very useful and is becoming more and more widespread (Guler, 2013). Geographical features such as soil type, soil impermeability, land use, vegetation, watershed boundary and river network are influential and important in hydrological events, and these parameters can vary greatly depending on location. The GIS provides a great convenience in determining or defining and sharing these parameters (Sener, 2011). In this study, GIS was used to extract the bathymetry of the dam reservoir and to obtain the digital elevation maps of the study area (Özdemir, 2017).

The HEC-RAS is a free software and was used to produce the flood maps. Developed by USACE, HEC-RAS is a program that calculates 1-dimensional (1D) and 2-dimensional (2D) water surface profiles of continuous flows and models for discontinuous flows. Hydrological calculations must be made before hydraulic modelling in HEC-RAS.

In addition, solids transport and water quality can be modelled in the HEC-RAS program. The HEC-RAS program is a hydraulic analysis program where one can simulate the progress of water in 1 and 2 dimensions, with the help of data such as determined roughness values, flow rate per unit time, and land topography. The HEC-RAS package program produced by USACE has been used to obtain flood hazard maps by establishing a

2-dimensional (2D) analysis model for the Gökçe Dam failure. Equations 1 and 2 are the most commonly used equations in dam failure analyses made in the HEC-RAS program.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad (1)$$

$$I_E = I_0 - \frac{\partial y}{\partial x} - \frac{v \partial v}{g \partial x} - \frac{1}{g}\frac{\partial v}{\partial t} \quad (2)$$

where A = current area through which the flow passes; Q = total flow through the area; q = flow through the unit width of the channel; v = average flow velocity through the channel; x = channel length; y = flow depth; t = time; I_E = energy line slope; I_0 = channel base slope and g = gravitational acceleration.

The Manning's coefficient values for the study area have been calculated separately for each region (such as city, field, forest, building, etc.) and added to the HEC-RAS program. The Manning's n values of the study area are presented in Table 1. The characteristics of Gökçe Dam reservoir is given in Figure 6. The minimum reservoir area is 0.225 km^2 and the normal reservoir area is 1.207 km^2. For overtopping and piping methods, the dam failure graphics are presented in Figure 7. Table 2 presents the breach parameters used according to overtopping and piping methods.

Table 1. Manning's n value of study area.

Area	Description	n
River channel	Clean, straight, full stage, no rifts or deep pools (but more stones and weeds)	0.035
Floodplain	Short grass	0.030
	High grass	0.035
Tress	Dense willows, summer, straight	0.150
Brush	Scattered brush, heavy weeds	0.050

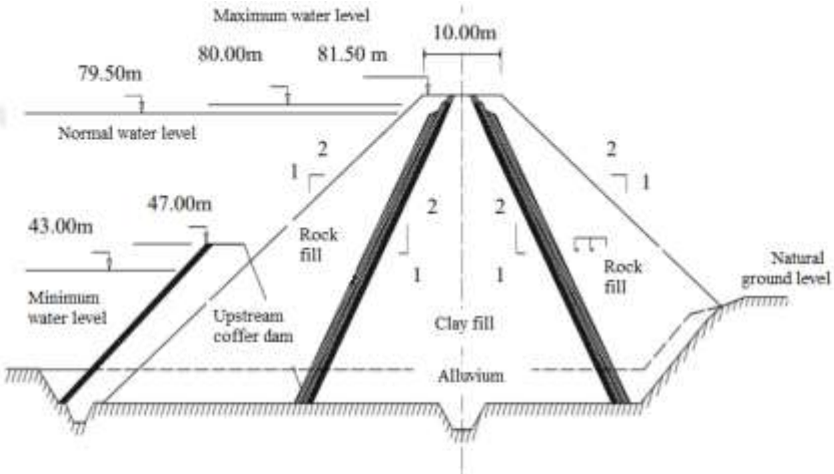


Figure 6. Gökçe Dam cross-section (Agricultural and Forest Ministry, 2018).

Table 2. Breach parameters of overtopping and piping methods.

Breach Parameters	Failure Mode	
	Overtopping	Piping
Breach Method	User Entered Data	User Entered Data
Center Station	350	350
Final Bottom Width	26	130
Final Bottom Elevation	42	42
Left Side Slope	0.5	0.5
Right Side Slope	0.5	0.5
Breach Weir Coef.	1.44	1.44
Breach Formation Time (hrs)	1.34	1.01
Initial Piping Elevation	-	50
Trigger Failure (WS Elev)	80	80

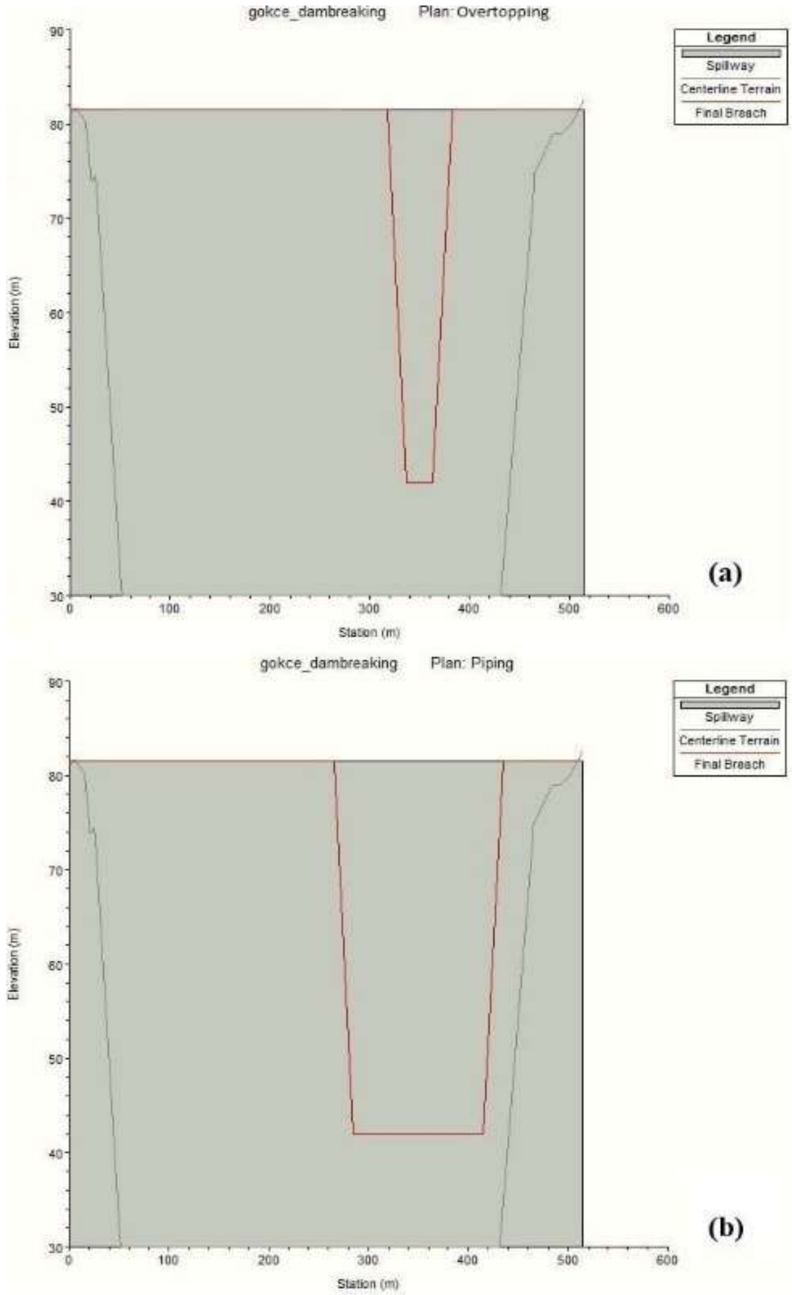


Figure 7. Dam break graphics (a) overtopping and (b) piping.

Gökçe Dam failure flood analysis

In the HEC-RAS program used for dam failure analyses, there are 5 types of failure scenarios, as stated by Mac Donald, Froehlich (1995-2008), Von Thun and Gillete (1990) and Xu and Zhang (2009).

MacDonald and Langridge-Monopolis studied 42 dam failure cases to find the relationship between dam failure parameters (MacDonald & Langridge-Monopolis, 1984). They correlated parameters such as the volume to be discharged from the dam's upstream (V_w, m^3) during the failure (t_f, hour), the volume of material coming out of the body after the dam failure (V_m, m^3), and the water height between the water level before the dam collapse and the base height of the dam failure (h_w, meters). They stated that the dam failure slopes can be taken in the ratio of 1 horizontal and 2 vertical.

Froehlich (1995) developed dimensionless estimation equations for estimating mean rift width, mean rift edge slope slopes, and rift formation time. The reservoir volume is based on the characteristics of the dam, including the water height above the breach floor, the breach height, the dam crest and breach floor width, the coefficient for over or underrun demolition, and the presence or absence of a core wall. Froehlich (1995) also concluded that all other factors being equal, breaches due to overhang are larger and the rate of lateral erosion is faster than those caused by other causes (Wahl, 1998).

In 2008, Froehlich updated his previous relations based on the new data added. Using the data of 74 earth fill, zoned earth fill, clay core earth fill and rock fill dams, the relations of mean breach width, side slope slopes and failure time have been developed.

Xu and Zhang (2009) determined that, according to the failure scenarios of 182 dams, erosional soils have a significant effect on failure time, breach width and peak flow rate (Xu & Zhang, 2009). Xu and Zhang (2009) examined 182 embankment and rockfill dams in China and in the United States, of which approximately fifty percent were dams higher than 15 m (Xu & Zhang 2009).

Von Thun and Gillette (1990) and Dewey and Gillette (1993) used data from Froehlich (1995) and MacDonald and Langridge-Monopolis (1984) to develop predictive relations for breach slope, mid-height breach width, and failure time. They suggested that the slopes of the rift edge can be accepted as 1:1, and 1:2 or 1:3 (*h*:*v*) may be more appropriate for dams with cohesive surfaces and very large cohesive cores. (Wahl, 1998).

Von Thun and Gillette (1990) analyzed 57 dam failure records and suggested that the mean dam failure width ($\bar{B}$, meters) can be found as the sum of the water height in the reservoir above the dam failure base (h_w, meters) and a coefficient dependent on the reservoir volume (C_b, meters) (Von Thun & Gillete, 1990). They stated that dam failure side slopes can be taken as 1 horizontal and 1 vertical in general, but it is more appropriate to take 1 horizontal and 2 vertical, and 1 horizontal and 3 vertical for cohesion-covered dams or dams with large cohesion cores.

In this research, the Von Thun and Gillete (1990) failure scenario was applied, since it can be used with a large crest width and is suitable for the structure of the dam under study. In addition, it was the chosen method both because it contains too many data sets and it is the most common method used in the literature. In their simulation, the researchers found that the dam was completely demolished in the failure event. They also proposed two different equations depending on the dam material type, in order to find the duration of the events. The Gökçe dam area was divided into 5*5 square areas in order to obtain the flood spread maps after the dam failure. Figure 8 shows the depth-time graph formed due to the dam failure and downstream of the dam, in the case of a possible failure of the Gökçe dam, according to the piping and overtopping methods. Accordingly, the time to reach the peak current in the piping method will be sooner than in the overtopping method. At the end of the 9-hour period, it is seen that the base period of the hydrograph has come to an end. From the same graph, it is seen that the ascending and descending curves at the depth downstream have a very steep slope, and the withdrawal curve is more oblique and long-term.

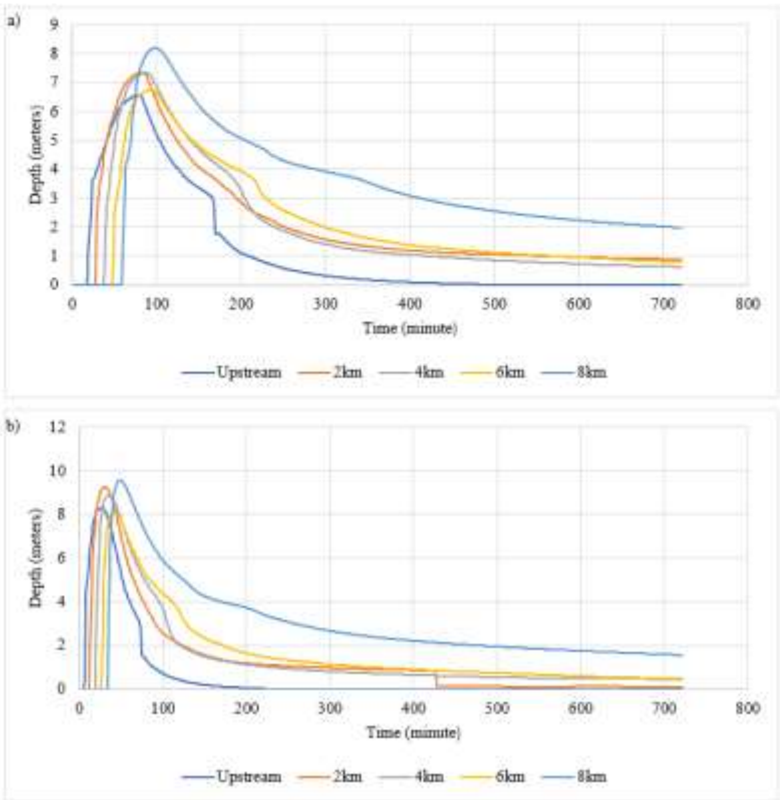


Figure 8. Depth-time graphics (a) overtopping method and (b) piping method.

The velocity-time graphics according to these two methods are presented in Figure 9. Looking at the graph, it is seen that the highest speed is reached at 2 km, and the lowest speed at 8 km, in both methods. In addition, in the piping method, the speeds at all distances are faster than in the overtopping method, so the time to reach the downstream is shorter.

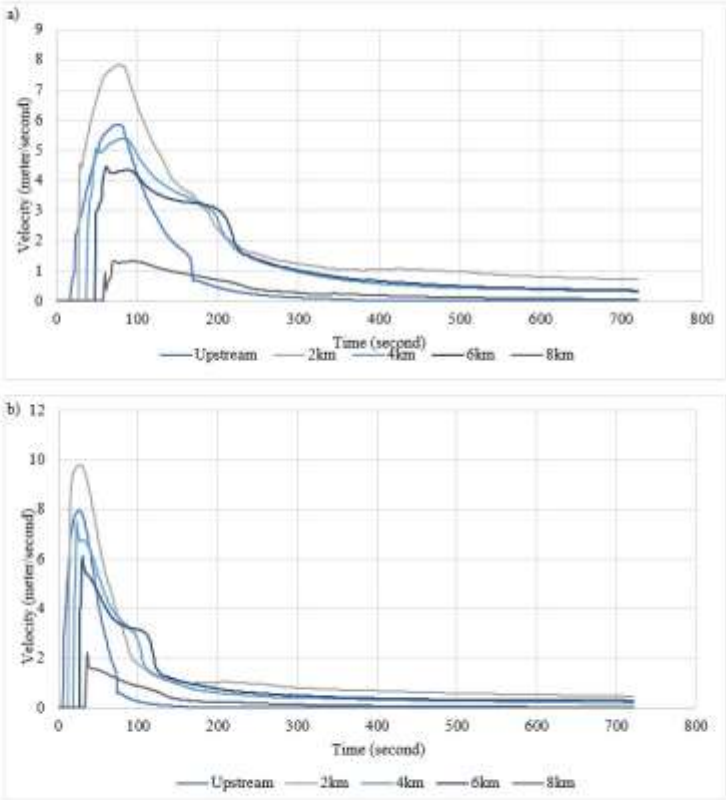


Figure 9. Velocity-time graphics (a) overtopping method and (b) piping method.

Figure 10a and 10b show the flood wave propagation times along the riverbed in the event of the Gökçe Dam failure according to the piping and overtopping methods, respectively. Figure 10a and 10b show the boundaries and water depth values that will be formed by the highest water surface elevations that are expected to be formed in the event of the Gökçe Dam failure. According to this, it has been observed that most of the possible village roads that can be used for transportation to other villages in case of a disaster may remain under water.

Considering the central district, it can be stated that the population living there may be at risk if the dam fails. It can also be said that in the downstream part of the city, where urbanization is more intense, this situation may affect the daily life.

When the maximum water depth map on the right is examined in Figure 10c and 10d, the flood depth along the river varies between 5-10 m, while it varies between 3-5 m and 2-3 m in the regions close to the river. The regions with the lowest flood water depth are closer to the city center. At the time of the flood, even if the water level is low, it will affect the daily life in the city. The flood maximum water maps and the maximum velocity maps can also be used as flood spread maps. As it can be understood from the two velocity maps (Figure 10c-10d), the flood reaches the highest speed from the dam and then continues towards the city center with decreasing speed. It should not be forgotten that, as the speed of the flood increases, its destructiveness also increases. The Yenimahalle district, which is subject to the highest rate of flood, is at a greater risk in terms of flood rate.

Figure 10e shows the flood maximum velocity for the overtopping method and the 10f shows the flood maximum velocity for the piping method. In the piping method, the speed reaches higher values in a shorter time compared to overtopping.

The estimated flood velocity that will occur in the event of the Gökçe Dam failure is shown in Figure 10e and 10f. It has been found that there are many houses along the downstream of the dam, especially in the stream bed. In order for these settlements to be prepared for a possible disaster, emergency action plans should be prepared. In the areas with high flood velocity, the destructiveness of the flood will be higher. Figure 11 shows the hydrograph of dam failure according to both overtopping and piping methods.

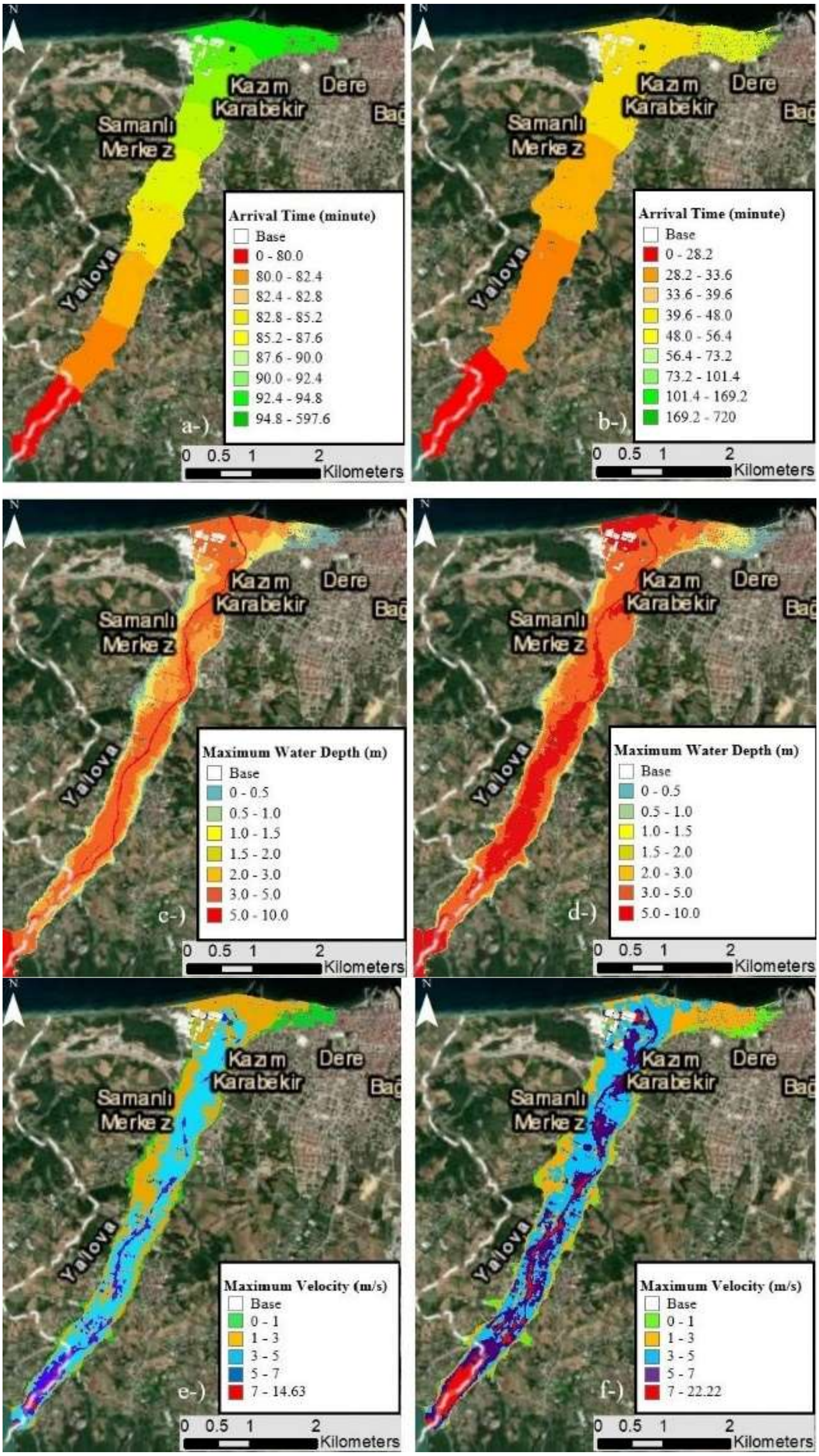


Figure 10. (a) Flood arrival time map for overtopping method (b) flood arrival time map for piping method (c) flood maximum water depth map for overtopping method (d) flood maximum velocity map for piping method. (e) flood maximum velocity map for overtopping method (f) flood maximum water depth map for piping method.

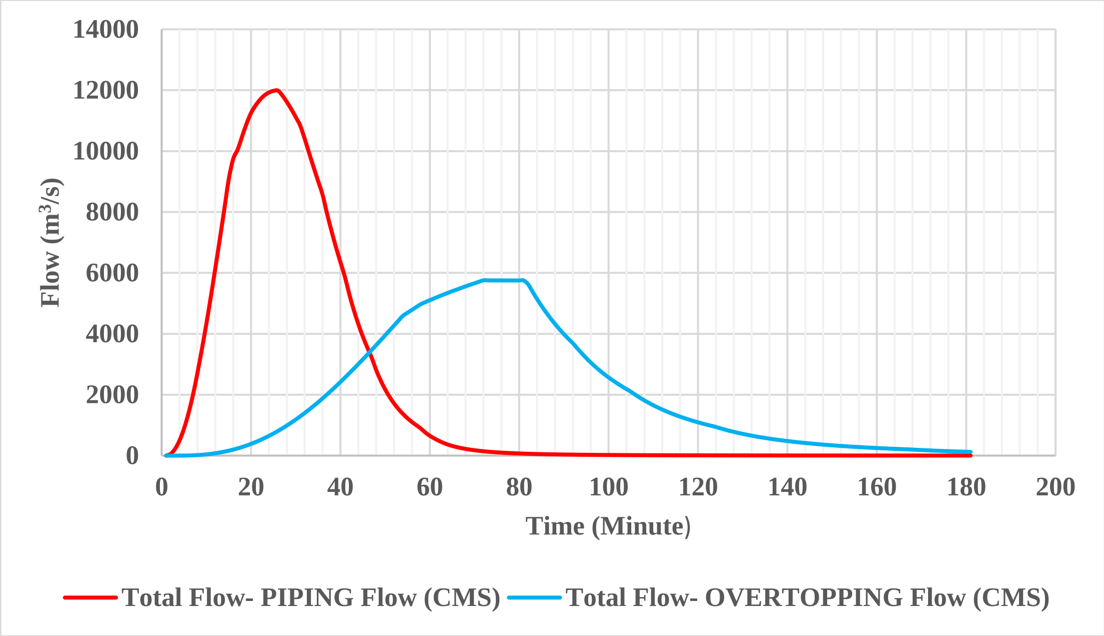


Figure 11. Hydrograph of dam failure for piping and overtopping methods.

Damage analyses

Damage analyses were made using the water depth damage factor curves created by Van Eck and Kok (Van Eck & Kok, 2001). In the depth-damage curves of Van Eck and Kok (2001), there are four categories: industry, residential buildings, roads and agriculture. In addition, this method was chosen because it is frequently used in the literature and it best reflects the damage calculations for the buildings within the scope of this study. The depth damage curve used in this study is presented in the Figure 12 below. After determining the damage function from these curves, the damage factor can be read depending on the water depth. In the study, since the structures located downstream of the dam are residences/buildings, the damage is in function of the housing structures and the related damage factors were used. After the damage factors were determined, the damage percentages were multiplied by the floor area of the buildings exposed to flooding and the damage amounts were calculated. There is a large area that is subject to the risk of flooding in the event of a possible failure of the Gökçe Dam, and there are many structures of different types (residential, government, commercial, etc.) in this area. For this reason, the damages occurred in the buildings were designated by using the approximate unit price list of the 3rd class A group buildings (residence, commercial building, school, kindergarten, etc.), published in the Official Gazette (2021) dated March 24, 2021 by The Ministry of Environment and Urbanization and the Ministry of Interior of the Republic of Turkey. The unit construction cost of the buildings has been accepted as 1360 TL m^{-2} and the content cost (all things inside a building, such as equipment, furniture and other goods) is not included in this price. (TL refers to Turkish Lira. At the time of writing, 1360 TL is equivalent to approximately $100, according to the average lira-dollar exchange rate). Therefore, the damage inside the buildings has not been calculated within the scope of this study. The currency used in the calculations is dollar. In the Official Gazette No. 17886 published on 02.12.1982, the depreciation rate was taken as 20% according to the assumption that the buildings are generally reinforced concrete carcasses and between 16-20 years of age. The structural damage due to the water depth in the study area was examined in 6 classes: as 0-1, 1-2, 2-3, 3-4, 4-5 and greater than 5 meters. Analyses were made over the total area of the buildings in each range. Table 3 presents the number of buildings and the total area for two methods. Damage amounts calculated for each building were also multiplied by the unit price and depreciation, and the estimated cost of damage was calculated. Damage percentages are 10% for 0-1 meters, 15% for 1-2 meters, 20% for 2-3 meters, 30% for 3-4 meters, and 70% for 4-5 meters and beyond 5 meters. Calculations were made as 100% for the water depth.

Results and discussion

Dam failure is an important and complex event that can cause major disasters. The mechanisms of dam failure are not yet fully understood, so a lot of work needs to be done on this subject. Gökçe Dam, located in

Yalova, Turkey, is an important source of water for the region. According to the data of the Turkish statistical institution, Yalova province ranks first in Turkey in terms of water use per capita. For 2040, the per capita water use is foreseen as 1283 Turkish Liras/person-day. Yalova's current daily water use per person is 200 litres. Water use in 2040 is predicted to be six times higher than the current water use of Yalova. In this study, the dam failure is studied using the HEC-RAS model and according to two different situations: overtopping and piping. HEC-RAS results were transferred to the GIS environment, the number of affected houses was determined, and then the economic losses that would occur in buildings and houses have been calculated.

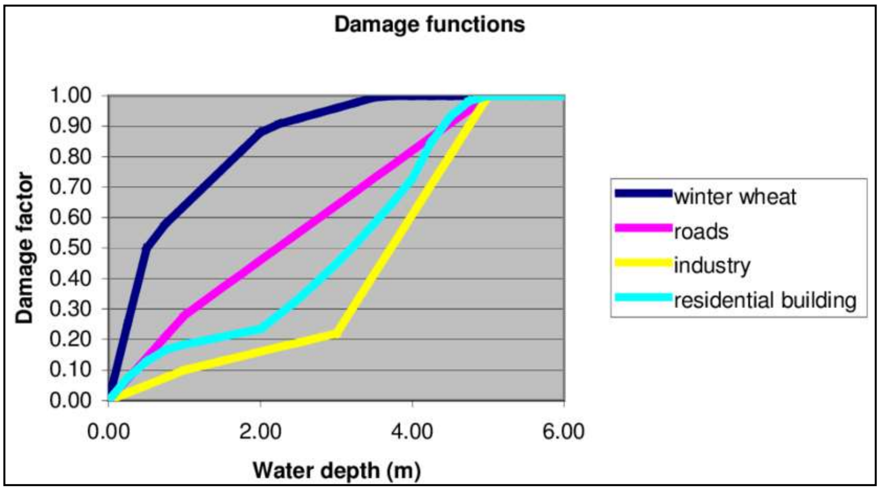


Figure 12. Damage functions from Vrisou Van Eck and Kok (2001).

Table 3. Building numbers and total area.

Class	Number of Buildings Overtopping	Number of Buildings Piping	Total Area (m^2) Overtopping	Total Area (m^2) Piping	Total Damage Overtopping ($/$m^2$)	Total Damage Piping ($/$m^2$)
0-1 m	723	539	187211.62	167999.89	374423.24	3359997.8
1-2 m	684	605	174290.88	164791.22	522872.64	3295824.4
2-3 m	713	711	187488.47	156255.12	749953.8801	3125102.4
3-4 m	569	703	363487.97	178063.12	2180927.82	3561262.4
4-5 m	232	578	230958.66	309144.29	3233421.24	6182885.8
>5 m	10	511	145.49	317012.49	2909.8	6340249.8

Accordingly, as a result of a dam failure, even at the lowest water level, many structures would be damaged. Also, the lack of water could become a major problem as a result of the destruction of an important water source in the region. The failure of the dam poses a great danger to the people, living beings and the properties in the region. Therefore, the results of this study are crucial in terms of taking the necessary precautions and protecting the people's lives and properties.

When the two methods used in this study are compared, it is observed that both the water level and the flow rate increased more in a shorter time in the piping method. The propagation/advance time of the additional flood was also shorter in the piping method. In the economic damage analysis, the number of buildings affected by higher water levels in the piping method is higher than in the overtopping method, and the level of possible damage accordingly also increases. Through these data, it is clear the importance of conducting more studies on the piping method and its consequences.

According to the results obtained:

In case of the failure of Gökçe Dam, an area of approximately 5.46 km^2 may be affected by flood waters. There are risks in terms of both economy and population, due to the presence of agricultural lands and residences in the region. In the event of the Gökçe Dam failure, the peak height in Yenimahalle occurs in approximately 1 hour after the beginning of the simulation. After flood passes Yenimahalle, it travels approximately 1 km at intervals of 2.4 minutes. It is seen that the maximum water height can reach up to 5 meters in the places where settlements are dense. It is expected that the maximum water depth in the basin will rise up to 10 m in the risky areas.

Everything considered, this study has emphasized the importance of disaster emergency rescue operations to be carried out by determining the dangerous areas in the event of a possible disaster related to dam failure. It also suggests that city planning or flood prevention structures should be designed according to the flood risk.

Conclusion

Damages caused by floods reach enormous dimensions, and their effects can be devastating, especially if they occur after dam failure. Dam-break studies are important for the determination of dam construction site and disaster management plans. Risk reduction studies should be carried out by analyzing dam failure scenarios, estimating possible consequences and risks.

In this study, the flood hydrograph and flood inundation areas that may occur in the event of the Gökçe Dam failure were determined, so the risk levels, flood risk maps and economic damage analyzes were assessed. Similar studies can contribute to building disaster-resilient cities, and can help mitigate the devastating economic damage from these disasters.

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