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Production of flood risk maps: Ayancık Stream Example

Elnaz Najatishendi[*1], Emine Müjgan Ergene[1], Melis Uzar[1], Füsun Balık Şanlı[1]

[1]*Yildiz Technical University, Department of Geomatics Engineering, Türkiye*

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Abstract

Natural disasters are events that negatively affect human life and cause material and moral damages. As in the rest of the world, one of the biggest natural disasters after earthquakes in our country is floods. The flood event turns into a disaster in cases caused by human interventions such as the change of the river bed, the increase in the construction on the riversides, and the blocking of the river perpendicular to the flow direction. In this study, risk maps for floods with different return intervals (25, 50, 100 years) were produced with GIS for Ayancık stream in Sinop province. As a result, when the flood risk maps were analyzed, the regions located in the floodplain were considered very risky regions. According to the results obtained, the flood disaster reaches a depth of 7 meters. Ayancık Stream and its surroundings are a very risky area exposed to floods as they have a maximum depth of 3.5 m. In addition, flood risk areas with 50 and 100-year return period floods, increase 3.71 and 12.83 percent, respectively, from 25-year return period flood risk areas.In addition, it was concluded that the majority of the areas affected by the floods in all three turning ranges within the scope of the study area are located in the very risky region, while the extreme risk areas are less than the other risky groups.

1. Introduction

Natural or human-induced events that cause life, economic and social losses for people and cause interruption of public life and human activities for a certain period of time are defined as "disaster" [1]. Many countries, depending on its geography, climatic conditions, and geological and topographical features, are exposed to meteorological natural disasters that result in significant loss of life and property from time to time. One of these natural disasters is flooding.

Floods are one of the natural disasters that cause significant loss of life and property in our country and many parts of the world. Major floods in Turkey are a combination of regional climate, topography and basin area factors. As we move inlands from the seas on our north, west and south coasts, the humidity in the atmosphere decreases. Heavy rains and large floods occur in high elevation areas perpendicular to the humid air flow, such as on the Black Sea and Mediterranean coasts. Floods in large basins areas are formed by the accumulation of rain as well as melting snow, but in small basins are mainly caused by rainfall [2].

Although the main factor of flood events is known as precipitation, the destruction of the natural features of the river basins day by day, the intense use of land and the wrong interventions on the river beds cause even the normal precipitation for the basin and river beds to cause floods. In addition, engineering structures built on rivers sometimes lead to the evaluation of features that did not pose a risk before as a risk. This causes some new plans to be considered in risk management studies for land uses near the river bed [3].

Risk management, which is a systematic process, consists of risk identification, risk analysis and determination of the amount of risk. Efforts to minimize the loss of life and property in a possible flood and to reduce the harmful effects of the flood can be carried out with risk management in flood areas.

In risk management studies; hazards and risks are determined, risk scenarios are prepared, protection and mitigation measures are selected, the results are

* **Corresponding Author**

*(elnaz.najatishendi@std.yildiz.edu.tr) ORCID ID 0000-0001-7901-5640
(mujganergene@gmail.com) ORCID ID 0000-0002-1118-0006
(auzar@yildiz.edu.tr) ORCID ID 0000-0003-0873-3797
(fbaliksanli@gmail.com) ORCID ID 0000-0003-1243-8299

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presented with current maps and graphics, resources and opportunities that can be used are determined, and decisions about the most appropriate options and priorities for disaster protection and disaster response are eliminated and implemented [4].

Various methods and tools have been developed within the scope of flood risk management in the world. One of the most important of these tools is geographic information systems. The use of GIS, especially in the analysis of risk scenarios, is increasing day by day because the use of remote sensing and GIS technologies together in wide geography makes this tool attractive. Desalegn et al. [5] used GIS and HEC-RAS model for mapping flood inundation areas at Fetam River, Upper Abbay Basin, Ethiopia. As a result, they obtained flooded areas along the side of the Fetam River are 27.31, 24.85, 20.47, 17.34, and 13.78 km2 for 100, 50, 25, 10, and 5 years return periods, respectively. Moreover, Losub et al. [6] performed flood risk maps analyses in northern part of the Neamt county, North-Eastern region, Romania by using HEC-RAS method with the HEC-GeoRAS. As a result, they determined the correlation with the field situation and flood risk in a very high proportion. According to the simulation; for a 1% occurrence flood, almost 123 damaged households and a number of 147 damaged buildings have been detected.

In the study area, urbanization was established around the Ayancık stream. For this reason, it is foreseen that the first area to be affected in the event of a flood will be the district center where urbanization is located. Our aim in this study is to scientifically prove that the city center located around the Ayancık stream is at risk of flooding, and thus to determine the areas where precautions should be taken.

In this study, the production and evaluation of risk maps were carried out with the integration of remote sensing and GIS. Precipitation, soil, land use, and digital terrain model were used at this stage. As a result, flood risk areas were determined for the Ayancik region, and their impact on settlement areas was evaluated.

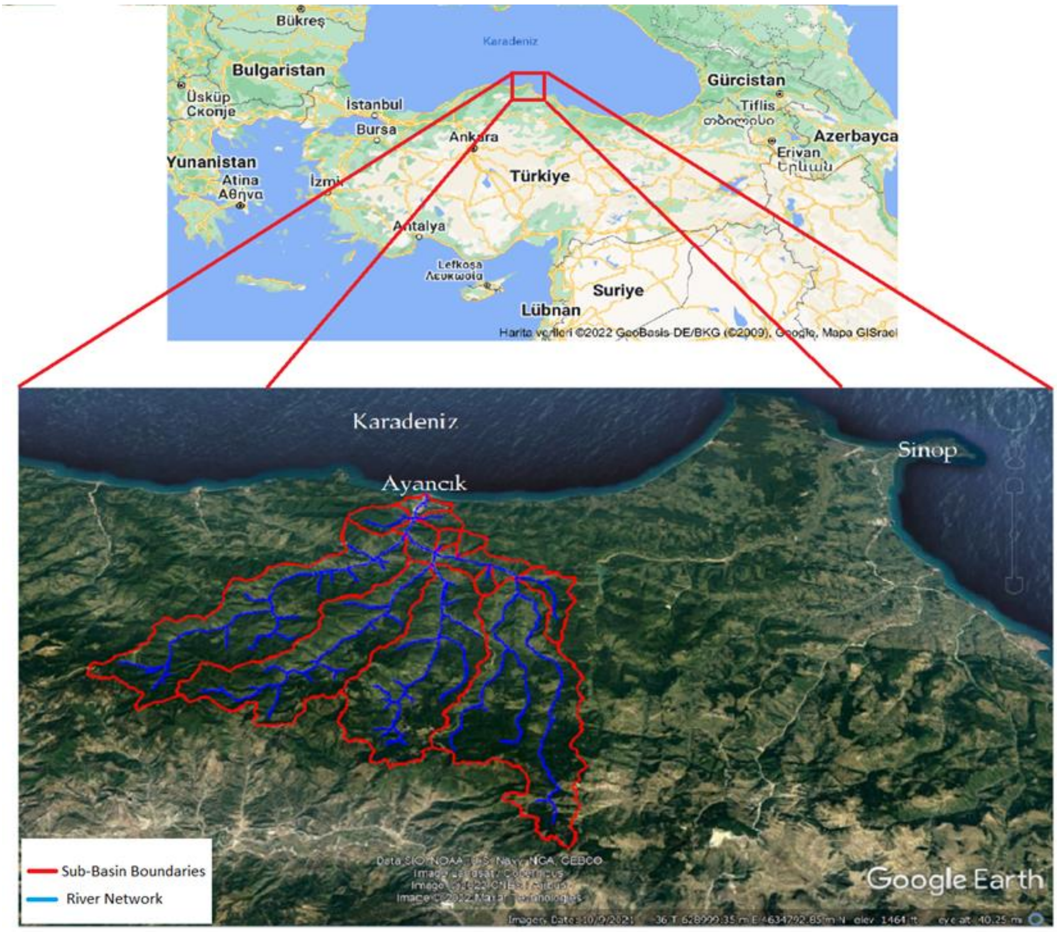

Figure 1. Ayancık stream precipitation basin settlement map

2. Study area and data used

Ayancık Stream is located in the Black Sea region and is connected to the province of Sinop. It is located at a distance of 47 kilometres from the province of Sinop and at a latitude of 41.9484 and a longitude of 34.5931 (Figure 1). In Figure 1, the Ayancık Stream basin and its sub-basins are shown with red lines, and Ayancık Stream networks are shown with blue lines. The basin area is 676.54 km^2 and the average height of the basin is 884.14 m, and it is a river pouring into the Black Sea. Ayancık region has a typical Black Sea climate, with cool and rainy winters and dry and humid summers. The annual average temperature is 14.0 C degrees. The highest average temperature is 22.2 °C in July, and the lowest average temperature is 6.6 °C in January-February. The annual average relative humidity is 72%, the humidity reaches its highest value at 76% in March, and its lowest value at 70% in June, July and December.

The annual average precipitation is 676 kg/m ^{2}, the highest precipitation is in December with 139.2 mm, and the lowest is in July with 34.9 mm. Its high parts are usually covered with snow during the winter season. Forests form the natural vegetation of the region. The vegetation is very rich and dense and differs according to the altitude zones. In the coastal part, broad-leaved forest texture, maquis and heaths and cultivated plants are common. As it rises from the coast, coniferous tree and plant species gain density. There are pine, fir, oak, hornbeam, beech, ash, elm, linden, plane tree, chestnut, poplar and various maquis and shrub species in the forests [7].

2.1. Numeric Elevation Data

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is generally preferred in the creation of Digital Elevation Models (DEM) due to the advantage of having wider coverage and better temporal and spatial resolution [8]. The resolution of the DEM data used in this study is 6.7 m. DEM maps of the Ayancık Stream basin are given in Figure . ASTER global SYM (ASTER Global Digital Elevation Map – GDEM) has been published as the product of a joint project between the Japanese Ministry of Economy, Trade and Industry (METI) and the United States Aerospace Administration (NASA). The first version of the ASTER GDEM model was presented to users in June 2009. In the calculation of the model, it was obtained by evaluating the stereo-dual satellite images obtained from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) sensor on the Terra satellite of the NASA Earth Observing System (Eath Observing System-EOS) [9]. The quality and accuracy of ASTER GDEM global SYM versions are evaluated and reported by the ASTER evaluation working group, with 20 members led by the United States and Japan [10]. The ASTER GDEM V3 maintains the GeoTIFF format and the same gridding and tile structure as V1 and V2, with 30-meter postings and 1 x 1-degree tiles [11].

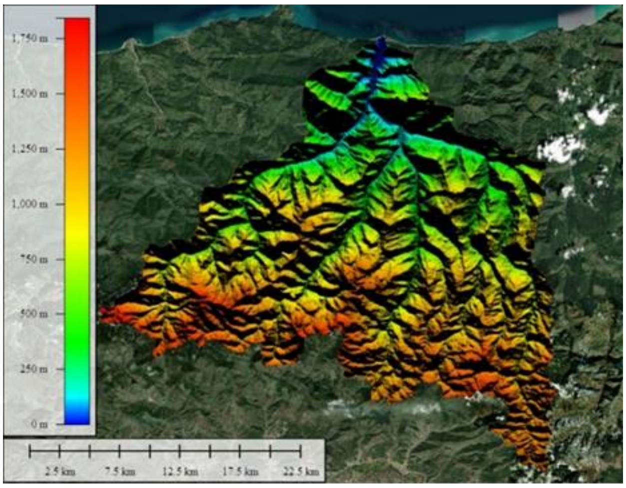

Figure 2. DEM maps of the Ayancık Stream basin

2.2. Precipitation Data

In this study, rain intensity values were obtained from rainfall intensity (i), rainfall duration (t) and recurrence time(T)(i-t-T) curves (Figure 3) of the Sinop meteorological observation station operated by the General Directorate of Meteorology (MGM). In addition, the precipitation values used with 25, 50 and 100 year return intervals and 24-hour periods, respectively, are given in Table 1 (In this study, rainfall values were obtained from the i-t-T curves (Figure 3) of the Sinop Meteorological Observatory, which operated by the General Meteorological Office (MGM). İn addition, the rainfall values used with return intervals of 25, 50 and 100 years and 24-hour periods, are given respectively in Table 1.

Table 1. Frequency analysis of 24-hour precipitation in Sinop station [13]

Recurrence Period (Year)	Precipitation (mm/hour)
25	4.5
50	5.5
100	6.5

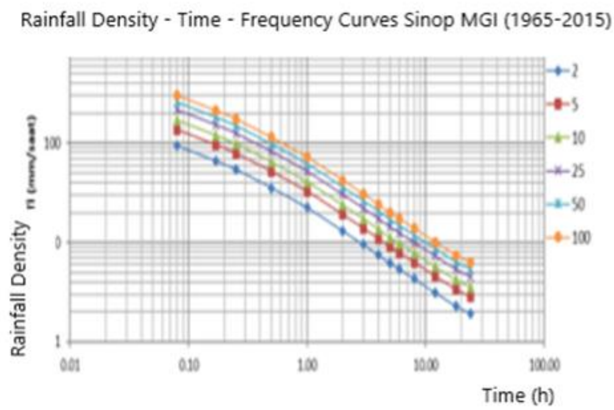

Figure 3. Sinop MGI i-t-T curves

2.3. Land Cover Map

Land cover maps were obtained from geophysical parameters derived from next-generation satellite images within the scope of the European Space Agency (ESA) Climate Change Initiative (CCI) projects (Figure 4).

These maps were prepared as a global land cover map with 300 m spatial resolution on an annual basis from 2016 to 2019, consistent with the global annual LC maps series from 1992 to 2015. The maps in netcdf format (2016 - 2019) were downloaded via the Copernicus Climate Change Service (C3S) Climate Data Store (CDS). In addition, C3S is implemented by the European Center for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission [12].

2.4. Soil Type Map

The Harmonized World Soil Database is a 2-degree grid with over 15,000 different soil mapping units combining information contained in current regional and national soil information updates (SOTER, ESD, oil Map of China, WISE) worldwide. raster database. This database includes the 1: 5 000 000 scale FAO-UNESCO World Soil Map (FAO, 1971-1981). As shown in Figure , the study area consisted of soil types B (Loam) and C (sandy clay loam).

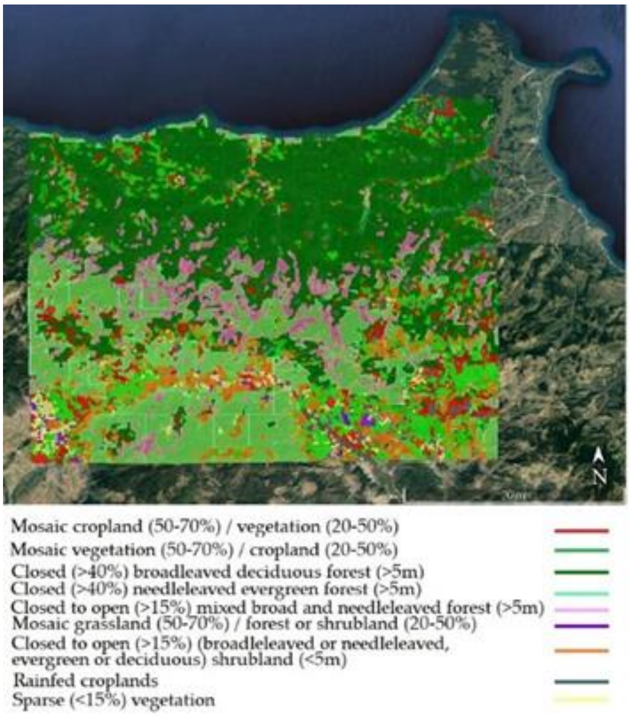

Figure 4. Ayancık basin land use map (ESA)

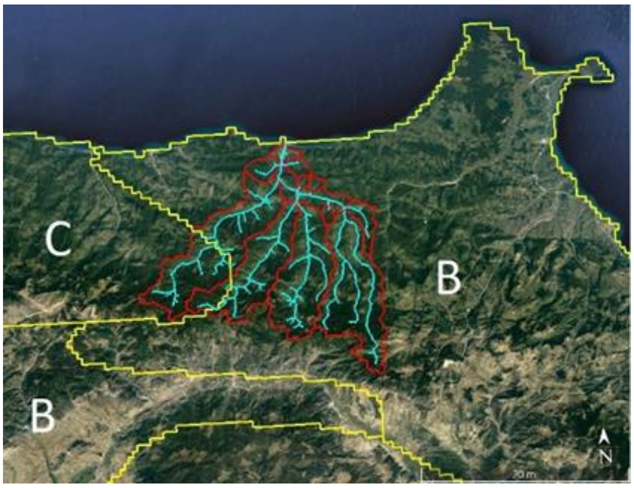

Figure 5. Soil type map of the study area

3. Methodology

A workflow chart is given to produce flood risk maps (Figure 6).

In the first stage for the production of flood risk maps, Digital Elevation Model (DEM), land use map, soil type map, and precipitation-intensity-recurrence curve of the study area were obtained to be used in hydrological and hydraulic models. In the second stage, Flood Hydrographs with various rotation intervals were obtained with the help of HEC HMS software using GIS data and Precipitation-Intensity-Recurrence curves (with The Soil Conservation Service (SCS) Curve Number (CN).

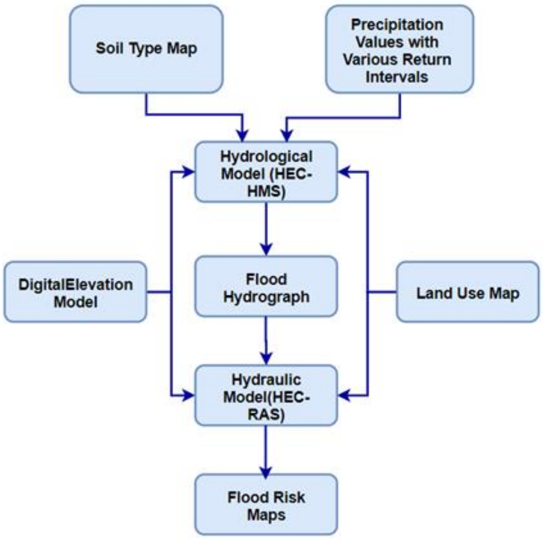

Figure 6. Workflow diagram for flood risk maps

The SCS CN method, also known as the flow curve number method, is a method developed by the Agricultural Soil Conservation Service of America, which estimates precipitation excess (direct flow).

$$S = (1.000 / CN) - 10 \text{ (mm)} \qquad (1)$$

$$Q = (P - 0.2S)2/(P+0.8S) \qquad (2)$$

The CN curve number is obtained from the SCS table (Table 2) and the S value is calculated from the equation. In this equation, P is the precipitation amount in mm and Q is the flow rate (m^3/s).

In the third stage, flood risk maps (HEC-RAS) consisting of precipitation values with 25, 50, and 100 year return intervals and 24-hour duration were obtained.

4. Results

Flood risk maps have been created for Ayancık Stream. After the precipitation data with various return intervals were obtained from the Precipitation-Intensity-Recurrence curves, flood hydrographs were obtained from the SCS curve number obtained from the land cover and soil type maps. Flood maps were obtained by creating a hydraulic model with these hydrographs. As a result, these maps were analyzed and evaluated in the GIS environment of the data obtained by remote sensing and photogrammetry, and risk classification based on depth was made.

4.1. Classification of Flood Risk Areas

Flood areas are classified according to the three critical depths of 0.6, 1.0, and 3.5m. For selecting critical depths, the height of school and public buildings from the ground is 0.6 m. If the flood depth is more than 1.0 m, there is a possibility of a loss of life. In addition, major damage is expected in agricultural production. The minimum threshold height for shelters and one-story buildings is usually 3.5 m. Hazard classification according to flood depth is given in Table 3.

Table 2. SCS Curve Number Table [14]

Land Use Description on Input Screen	**Description and Curve Numbers from TR-55** **Cover Description** Cover Type and Hydrologic Condition	% Impervious Areas	**Curve Number for Hydrologic Soil Group**			
			A	B	C	D
Agricultural	Row Crops - Straight Rows + Crop Residue Cover-Good Condition		64	75	82	85
commercial	Urban Districts: Commercial and Business	85	89	92	94	95
forest	Woods - Good Condition		30	55	70	77
Grass/ Pasture	Pasture, Grassland, or Range (3) - Good Condition		39	61	74	80
High-Density Residential	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
industrial	Urban district: Industrial	72	81	88	91	93
Low-Density Residential	Residential districts by average lot size: ½ acre lot	25	54	70	80	85
Open Spaces	Open Space (lawns, parks, golf courses, cemeteries, etc.) (4) Fair Condition (grass cover 50% to 70%)		49	69	79	84
Parking and Paved Spaces	Impervious areas: Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	one hundred	98	98	98	98
Residential 1/8 acre	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Residential 1/4 acre	Residential districts by average lot size: 1/4 acre	38	61	75	83	87
Residential 1/3 acre	Residential districts by average lot size: 1/3 acre	30	57	72	81	86
Residential 1/2 acre	Residential districts by average lot size: 1/2 acre	25	54	70	80	85
Residential 1 acre	Residential districts by average lot size: 1 acre	20	51	68	79	84
Residential 2 acres	Residential districts by average lot size: 2 acres	12	46	65	77	82
Water / Wetlands		0	0	0	0	0

Table 3. Type of flood risk [15]

Flood hazard no.	Flood depth, d, (m)	Type of flood hazard
T1	0<d<0.6	Little
T2	0.6<d<1.0	Middle
T3	1.0<d<3.5	A lot
T4	3.5<d	Extreme

4.2. Flood Hydrographs (HEC –HMS Model)

HEC-HMS software was used for hydrological analysis. This basin was divided into 10 sub-basins and the SCS method was applied. For this method, the curve numbers of the sub-basins were used from soil type and ground cover maps.

Ayancık basin was divided into ten sub-basins and 24-hour flood hydrographs were obtained for precipitation values at various return intervals for each sub-basin. These hydrographs are shown in Figures 7-9.

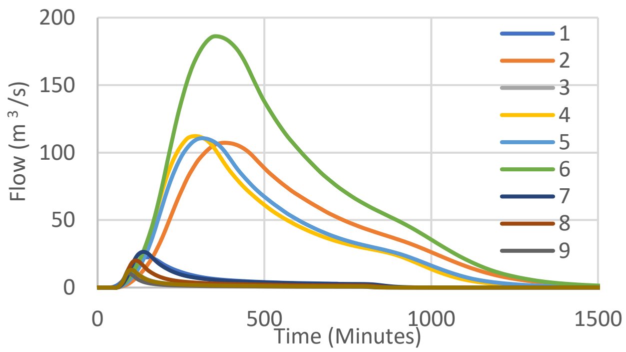

Figure 7. Flood hydrograph of Ayancık Stream sub-basins with 25-year return interval.

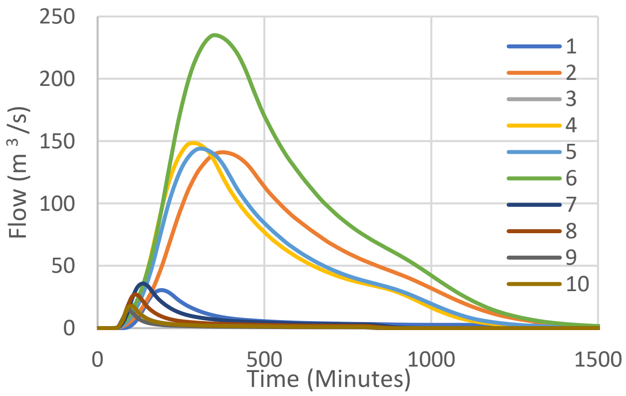

Figure 8. Flood hydrograph of Ayancık Stream sub-basins with 50-year return interval

4.3. Flood Maps (HEC-RAS Model)

In this study, HEC-RAS software was used to obtain flood maps. The prepared digital calculation mesh (10×10 m resolution) is shown in Figure 10. The boundaries of the floodplain were determined, as shown in Figure 10. In addition, the boundaries of discharges to the main bed of each sub-basin (10 sub-basins) are shown in the Figure 10.

As a result of 24-hour model studies, results were obtained for all three return intervals (25, 50, and 100 years), and flood spread maps are shown in Figures 11, 12, and 13. The area affected by each intermittent return flood was obtained and is given in Table 3. As shown in Figures 11, 12, and 13, the maximum water depth is 7 m. A combined view is given in Figure 14 to compare the flood risk maps generated by the modeled precipitations with various return intervals. According to the topographic condition of the creek, the area exposed to flooding is close in all three scenarios (Table 4). In this distribution map, the area shown in red represents the flood area with a 25-year return interval, the area shown in blue is the flood area with a 50-year return interval, and the green is the flood area with a 100-year return interval.

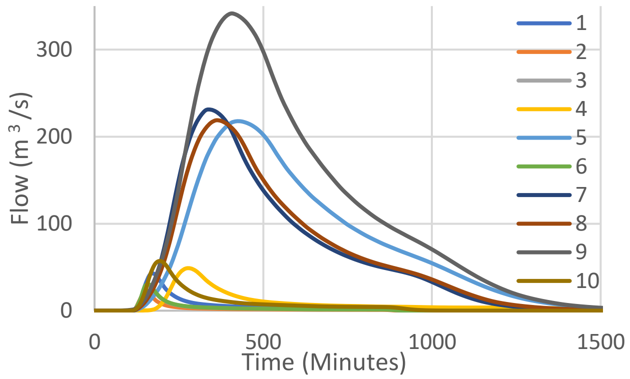

Figure 9. Flood hydrograph of Ayancık Stream sub-basins with 100-year return interval

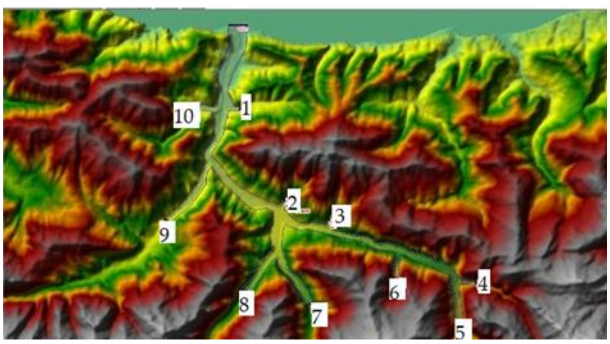

Figure 10. HEC-RAS model numerical computational network image and location of borders

Table 4. Flood maps obtained as a result of various return ranges

Return range (year)	Area (km ^{2})
25	3.178
50	3.296
100	3.586

5. Conclusion

Ayancık Stream is an important study area due to its regional and climatic characteristics. In this study, three scenarios, for 25, 50, and 100 year intermittent rain, were considered. The flooded areas are divided into three critical depths of 0.6, 1.0, and 3.5 m. Accordingly, 0-0.6 m deeplow-riskk zone, 0.5-1.0 m deep medium risk zone, 1.0-3.5 m deep high-,risk zone and more than 3.5 m depth extreme risk zone are classified into four groups.

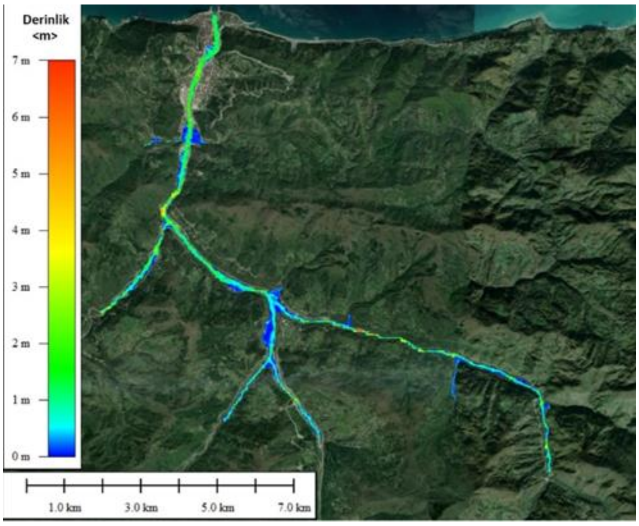

Figure 11. Ayancık creek flood spread map with 25-year return interval

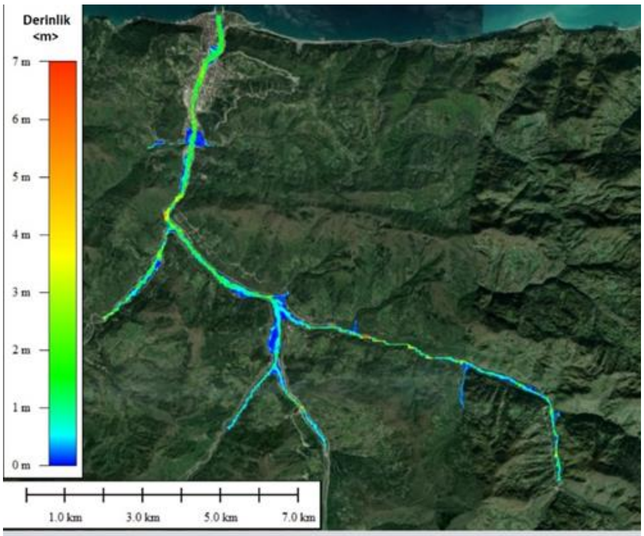

Figure 12. Ayancık Stream flood spread map with 50-year return interval.

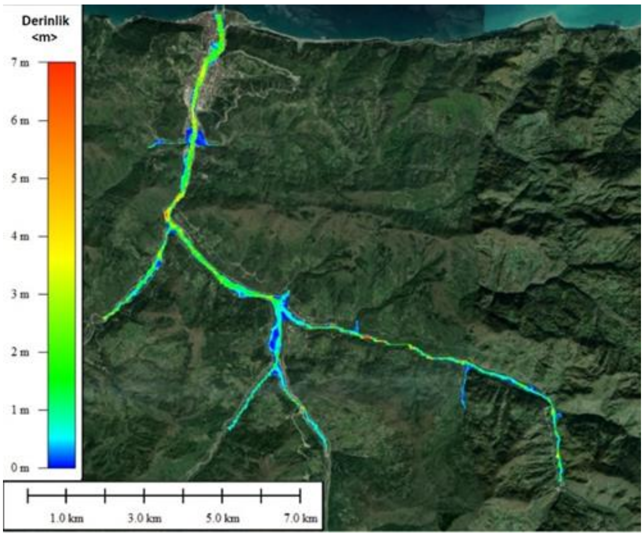

Figure 13. Ayancık creek flood spread map with a 100-year return interval

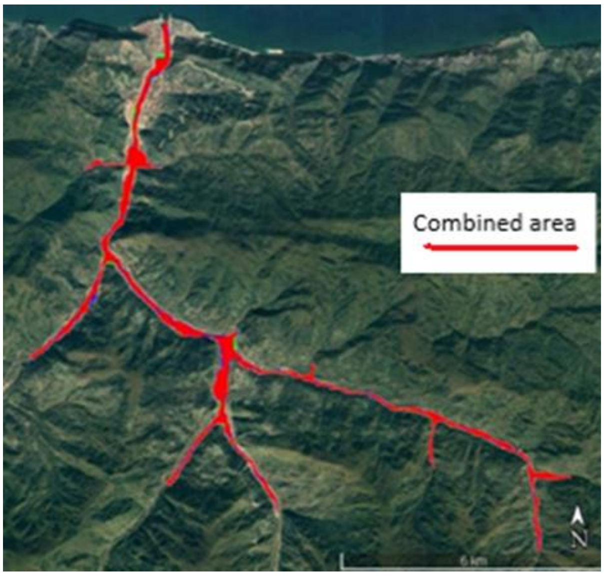

Figure 14. Combined view of risk maps.

In all 3 cases, the depth to which the flood will reach is 7 m, and most of the flood area is below the depth of 3.5 m. This shows that the floodplain of the creek will be located in a very risky region if precipitation with 25, 50, and 100 year return intervals occurs.

As a result of the analysis, it is suggested that urbanization should be controlled in areas close to the floodplain (in risky areas) so that the settlements located in the downstream region of the stream are not affected by the flood. An important result is that urbanization activities should not be allowed in cases of T1, T2, and T3 (flood hazard No.). In the current urbanization situation, information should be given to the civil and authorized administrations living in the region for urgent measures using advanced technology warning systems. Within the scope of disaster management, the rapid evacuation of all kinds of obstacles reduces the discharge capacity of the region and the stream, for example, the existing boats at the exit to the sea during floods. The academic and scientific solution proposal is to take measures according to the current situation analysis by considering the important criteria integrated with remote sensing and GIS and predicting future floods and accommodation, residence, etc., critical in areas close to flood risk areas. Floods are big threat in human life for communities and individuals that should not be allowed. As a result, with the increasing importance of such studies, the risk of flooding will be prevented in the future.

Author contributions

Emine Müjgan ERGENE: Data download, Image processing, calculation, analysis and interpretation, Methodology, Writing, Visualization **Elnaz NAJATISHENDI:** Data curation, Image processing, Software, Validation. **Füsun Balık ŞANLI** and Anime **Melis Uzar DİNLEMEK**: Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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