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ORIGINAL PAPER

Modeling flood hazard impacts using GIS-based HEC-RAS technique towards climate risk in Şanlıurfa, Türkiye

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Abstract

Climate change triggering extreme weather events and the fact that settlements are at risk have made flood disaster analysis a more critical issue. The economic, social, and environmental risk areas of Karakoyun, Sırrın, and Cavsak streams located in Şanlıurfa city center were determined using flood risk analysis. Thus, it aims to determine low, medium, high, and very high probability flood areas in the area, to collect the necessary data for establishing early warning systems and precaution packages, and to create an infrastructure for similar studies. While performing the risk analysis, we used Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, $Q_{500,}$ and Q_{1000} flood recurrence flows of the mentioned streams. Many criteria were considered, including stream routes, natural water retention capacities, land topography, and general hydrological and geological features. In the light of the data provided, digital elevation models of the streams were created in the ArcGIS 10.3 program, all information was transferred to the hydraulic modeling HEC-RAS 5.07 software, and risky areas were determined by performing a 1D flood analysis. At Q_2 flow rate, Karakoyun has 7.09, Cavsak 2.67, Sırrın 6.603 $m^3\ s^{-1}$, and at Q_{1000} flow rate, Karakoyun has 167.550, Cavsak 90.77, Sırrın 151.298 $m^3\ s^{-1}$ hydrograph peak values. As a result of the analysis, it was appointed that there was a flood risk in many parts of the stream sections. The flooding phenomenon has happened to be one of the most devastating floods for economic and environmental damages that occurred in Şanlıurfa City in 2023. People lost their lives, and many were injured during flooding; also, the urban economy affected nearly $15 million in the region. The risk of residences, shopping malls, and commercial areas in the city is revealed spatially.

Keywords Climate change · Climate decision-making · Hydrological modeling · Flood monitoring · Mitigation strategies

Extended author information available on the last page of the article

1 Introduction

Vital impacts due to climate risks have been one of the most significant global problems over the past century (Corringham et al. 2022). The governments have been struggling with extreme events and several disasters, and it has been observed that climate change has steadily increased hazards such as storms, tornadoes, drought, floods, and forest fires in urban areas (Jahangir et al. 2019; Andor et al. 2020; Cea and Costabile 2022; Isinkaralar et al. 2023). Current studies point to an increase in annual disasters in recent years. Today, natural disasters that negatively affect all living things occur in different types in different parts of the world, causing loss of life and property (Gallego 2018; Jongman 2018). The most significant scale events that have occurred in the world in recent times are caused by both climate change and human activities. Since the energy from the sun is stored more in urban areas due to their impermeable and non-reflective structure, cities warm up more than their surroundings, causing sudden weather events. In addition, human activities increase the greenhouse effect. The changing climate parameters also increase the water vapor in the atmosphere, causing severe weather events. (Chen et al. 2021). Taking precautions against possible global disasters is a critical social and economic issue (Rehman et al. 2019).

On the other hand, floods constituted 43.4% of all disasters experienced between 1998 and 2017, and more than 2 million people were affected by flood disasters (Wallemacq et al. 2018). Türkiye is prone to earthquakes, floods, typhoons, droughts, fires, landslides, and lightning due to location, weather conditions, underground resources, and the land structure of the country. One thousand two hundred nine flood disasters occurred in the country between 1975 and 2005. Seven hundred twenty people lost their lives, and approximately 893,933 ha of land was flooded. According to the General Directorate of State Hydraulic Works (DSI), the most floods occurred 122 times in 2015, the highest loss of life was 164 people, and the most significant area under water was 201,100 ha, occurring in the flood in 1995 (DSI 2015). In addition to meteorological reasons, rapid urbanization activities seen in underdeveloped or developing countries are also practical in floods. In countries with intense activity in economic areas, unplanned urbanization occurs with industrialization and the development of many different sectors (Pralle 2019; Mukherjee and Singh 2020).

This research aims to collect the necessary data to determine the low, medium, high, and very high probability flood areas of the Karakoyun, Sırrın, and Cavsak streams in the city center of Şanlıurfa, where Türkiye's fertile agricultural lands are located and supported by a comprehensive irrigation project, Southern Anatolian Project known as GAP, and to establish early warning systems and precaution packages. As a very crucial city due to its social, economic, and geographical location, there have been many flood disasters and loss of life and property throughout history. Due to floods in history, bridges over the Justinian dam and Karakoyun were built (Kürkçüoğlu et al. 2013). The overflow of the Karakoyun Stream, located in the north and west of the city, fed by winter rains and flowing until the end of spring, caused great material and moral damage. Moreover, flood risk mapping was carried out with HEC-RAS software using different flood recurrence flow rates in the region with a history of severe floods. This phase marks the beginning of flood mitigation measures. Predicting reliable water levels is advantageous in preventing the damage caused by a disaster and developing response systems against possible damage. From a natural standpoint, models continue to evolve with today's technology. In this context, this study has the following research questions:

- Q^1: Can HEC-RAS software be used as a tool for flood risk modeling?
- Q^2: Can flood risk areas be predicted spatially?
- Q^3: What strategies can be developed for areas at risk of being affected by floods?

2 Literature review

Urbanization causes the deterioration of natural vegetation, the decrease of the permeable layers of the soil, the excessive use of land with inappropriate agricultural methods, and the destruction of forests and ecosystems, thus increasing the frequency and effects of flood disasters (Li et al. 2021; Liu et al. 2022). Unplanned urbanization causes buildings to be located on dry and side stream beds. Irregularly constructed structures prevent the removal of surface run-off water, causing the urban infrastructure to be inadequate and streams to reach rare flow rates under normal conditions, damaging the surrounding land and structures (Handayani et al. 2020). It can reduce the loss of life and property from disasters by taking precautions and protection methods (Bae and Chang 2019). While carrying out the review, flood risk must first be evaluated to identify trends and gaps. Large-scale studies associate flood risk with historical processes (Disse et al. 2020). However, this method requires a comprehensive data set. Instead, current research includes geographic information systems (GIS)-based analyses due to its advantages (Peng and Zhang 2022; Hagos et al. 2022). Earlier researchers have demonstrated that urban flooding events can be a severe threat and suddenly emerge as natural disasters in urban zones by Kumar et al. (2020), Madhuri et al. (2021), Theodosopoulou et al. (2022) and Manandhar et al. (2023). The current literature review shows that flood risk management is widely used for urban flooding. The network between identifying flood sources and relation is strong in Fig. 1. Therefore, flood risk was chosen to indicate risk assessment.

Flood inundation mapping is an effective tool for reducing exposure in flood risk management. In this context, risk assessments were applied in different geographies using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) model. There are numerous reports on assessing and evaluating the reasons for flood events (Ferguson et al. 2020). Given this, Zeleňáková et al. (2019) developed a model using HEC-RAS software for flood management in Kružlov. Mahmood et al. (2019) determined to estimate various floods in the Panjkora River via HEC-RAS and HEC-Geo-RAS.

Similarly, Garcia et al. (2020) examined flood impact analysis using a HEC-RAS 2D for Hurricane Harvey in Houston. In the Namara et al. (2022) study, where HEC-RAS software was used for Flood Inundation Mapping in the Upper Awash River Basin of Ethiopia, it was understood that the entire Awash Bello flood plain was flooded due to heavy rainfall. Some studies using the HEC-RAS software have found that settlements closest to the mouth of the river are more affected by floods than other areas further downstream. It has also been shown to have a strong correlation in reliably predicting future floods (AL-Hussein et al. 2022). Afzal et al. (2022) observed good agreement between simulated and observed flood extents in the Indus River Basin in a flood inundation modeling study by integrating HEC-RAS and satellite imagery. Tyler et al. (2019) systematically addressed identifying practical lessons to improve communities' resilience to future flood disasters in the USA in the future. They worked to prepare economic flood risk maps in regions where floods are

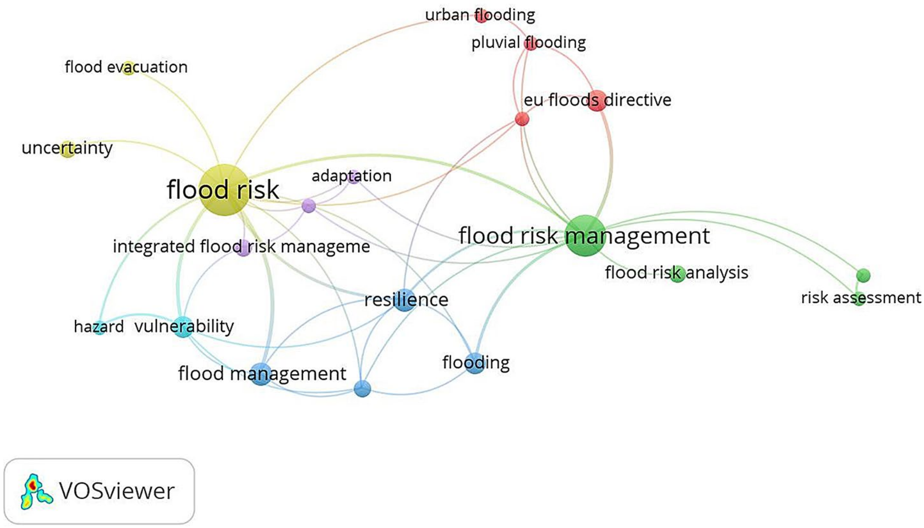

Fig. 1 Link-based visualization of the network, including flood hazard assessment via Vosviewer software bibliographic analysis

continuous, and data deficiencies exist. Another study also indicates that flood databases can be obtained by the water management and spatial planning divisions; the future orientation of Austria determined risky areas (Nordbeck et al. 2019). Abebe et al. (2019) showed a coupled flood-agent-institution modeling framework (CLAIM) with agent-based (ABM) models and illustrated how models are developed for flood risk management in Saint Martin. Maps of the region were determined from high-resolution photographs and overlaid on each other. The riskiest areas in terms of flooding were tried to be determined for the coastal flood simulations. Some vital factor parameters constitute a risk for the coupled ABM-flood model. Their simulation results show many examples of structural flood hazard reduction measures and evaluated scenario simulations. Waghwala and Agnihotri (2019) prepared the evaluation using a flood management map compatible with GIS in Surat, India. After the statistical evaluation of the current maximum values taken from the current flow observation stations in the program data, the risk analysis was performed to determine the status of the spillway capacities. Critically, a sub-database was created using the maximum rainfall values taken from the current flow observation stations, the project flood flow rate, and the flood flow rate that occurred in the past years. Rubinato et al. (2019) reported that a review of the risk analysis within increased urbanization in the UK and China was performed using the mean value first-order secondary moment and forward first-order secondary moment method. The spillway risk values were determined according to many different situations. There are numerous examples of how effective local public authorities are. The economically feasible spillway sizes were calculated for both the dams in the design phase and the suitability of the improvement of the existing dams that have been completed for making an in-depth assessment of flooding and plans for the management of flood risk in several cities (Costache 2019; Alves et al. 2019).

3 Methodology

In this study, meteorological, hydrological, and hydraulic information and data are required for the hydrological analysis of Sırrın, Karakoyun, and Cavsak Streams located in Şanlıurfa city center. They were obtained from Şanlıurfa Metropolitan Municipality and DSI Şanlıurfa 15th Regional Directorate. For flood analyses to be realistic, on-site measurements completed the missing parts of the data provided. Then, all information was transferred to ArcGIS 10.3, a GIS program, and Digital Elevation Models were created spatially. All cross-sections, like routes related to streams, can be obtained from the DEM data transferred to the HEC-RAS program. All data were modeled, and a two-dimensional flood analysis was performed. After the analysis, an attempt was made to create a model closest to reality using the zoning map obtained through Şanlıurfa Metropolitan Municipality to determine which quantity and proportion of buildings were damaged in which region.

Flood propagation maps show the areas that may be flooded in case of flood according to the determined flow rate, water height, water depth, and water flow rate. Thanks to the prepared flood risk maps it enables the creation of flood protection structures and the improvement of land use conditions as a result of modeling based on the intensity and severity of floods that have occurred in the past and those that may occur in the future. The following data were provided for modeling:

- Topographic maps,
- Hydrological data,
- Flood recurrence rates,
- Rainfall information,
- Previously obtained flood propagation zones,
- Geometric information,
- Cross sections information,
- Height,
- Spatial Analysis and Modeling (SAM),
- Hydraulic structures such as levees, sills, and contexts,
- Distribution areas and flood traces of historical floods.

3.1 ArcGIS 10.3 hydrology maps

In order to determine flood propagation areas, Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, Q_{100}, Q_{500}, and Q_{1000} flood values prepared according to the DSI Synthetic method were considered for various research. The ArcGIS software used in this study is a scalable integrated program developed by ESRI. This program includes many alternatives that enable ArcGIS data to be updated, created, viewed, managed, and analyzed. During the study, DEM data of all streams were created using the ArcGIS Desktop 10.3. This program can be obtained from the ESRI website.

3.2 HEC-RAS 5.07 modeling

HEC-RAS software provides the opportunity to work simultaneously with ArcGIS. It can model water surface profiles of natural streams and open channels in the light of data and perform one and two-dimensional flood analyses of stable flows and one and two-dimensional flood analyses of unstable flows. This program also provides the opportunity to determine channel capacities, sediment amounts, and distribution of floods, determine the levels at which floods can affect structures, perform water quality analyses and many hydraulic structure analyses, and present the results as reports and graphics. The HEC-RAS was developed in 1964 by the Hydrological Engineering Center (CEIWR-HEC) at the US Army Corps of Engineers (USACE) to obtain and control water surface profiles (Hosseinzadeh-Tabrizi and Ghaeini-Hessaroeyeh 2015; Vojtek et al. 2019). It has been used to create water surface profiles since 1995 and has been developed and updated with different versions daily for floodplain management (Bharath et al. 2021).

Additionally, the program offers three different current options when calculating water surface profiles. These are supercritical flow, subcritical flow, and mixed flow options. The study selected the flow regime for all streams as the mixed flow for steady state.

In order to determine the total flow rate and velocity coefficient in the section, the section is divided into subsections where the velocities are equal. While the section is divided into subsections in the HEC-RAS program, the transmission capacity is calculated for each section with Manning's Roughness Coefficient (MRC) formula, considering the sections where the channel roughness (n) changes.

Determining the "n" roughness coefficient is essential to obtain reliable results in preparing flood hazard maps and flood control projects. Different values were determined and used to determine the roughness coefficient as a result of observations and experiments. While the roughness coefficient in natural stream beds must be determined by considering many different factors, determining the coefficient according to the type of material used in artificial channels gives realistic results. It has been stated that the most appropriate method used by DSI in the country to determine the MRC in stream beds is the "Cowan Method," and a guide has been published by Cowan (1956). For the regulated routes in the streams subject to the study, the MRC in the channel and right-left floodplains was specified as 0.016; for the routes that were not regulated and left in their natural state, the roughness coefficient within the channel was stated as 0.070, and for the right and left floodplains it was determined as 0.040.

There are some limitations to the analyses performed in the HEC-RAS program. Accordingly, the flow is steady; the flow is considered to be slowly changing, one-dimensional, and the channel slope is small ($<1/10$). While the HEC-RAS program calculates the flow capacity of a section, the total flow rate value is usually calculated with the subsections on the right and left banks. It is calculated by adding the flow capacities of the main channel taken as a whole. As water surface profiles are determined in the HEC-RAS program, repeated solutions are made using the energy conservation equation, and the equation gives the energy loss value to determine the unknown water height in a section.

In the study, flood analysis was performed using the HEC-RAS 5.07 version. In the HEC-RAS program, the solution is made using the energy conservation equation, and the equations give the energy loss needed to analyze 1D stable currents. 1D continuity and momentum equations are analyzed using a semi-closed finite difference schematic for unsteady flow analysis. HEC-RAS 1D creates a model for stable and unstable flows, and while creating this model, data indicating the geometric and flow boundary conditions of the study area are transferred to the program and analyzed. As a result of the data and arrangements entered, the flood analysis was calculated using the mixed flow regime. The program analyzes water surface profiles using the standard step method equation. The energy equation is given in Eq. (1) by Walden (2004) and Zimmermann (2010).

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e$$
1)

Z_1, Z_2: base height of the main channel (m),

Y_1, Y_2: cross-sectional current depth (m s^{-1}),

V_1, V_2 (m s^{-1}): average velocities (Q/A).

Q: discharge (m^3 s^{-1}),

A: cross-sectional area normal to the direction of flow (m^2),

a_1, a_2: velocity weighting coefficient-Coriolis coefficient or kinetic energy correction coefficient,

g: gravity acceleration (9.81 m s^{-2}),

h_e: energy loss height (m).

2, 5, 10, 25, 50, 100, 500, and 1000-year recurrent flood flows of Cavsak, Sırrın, and Karakoyun Streams were considered for hydraulic modeling. The flow rates used for hydraulic analysis were obtained from the DSI 15th Regional Directorate and used in the analysis. The flow rate values used are shown in Table 1.

In order to define and run a hydraulic model in the HEC-RAS program, geometric data of the flow or flows must first be entered into the system. The route lines of the streams and the cross sections on these lines, channel lengths, and energy losses occur for many different reasons; information about bridges and culverts on the stream route and right and left bank areas constitute geometric data. The X direction, taken at regular intervals along the route perpendicular to the flow direction, creates cross sections by showing the length of the section, and the Y direction shows the height information.

All cross-sections are created perpendicular to the flow direction, and these cross-sections play a critical role in the analysis because they reflect the hydraulic properties of the basin. In order to make the analysis results accurate, an effort was made to take cross-sections up to the extreme points that are likely to flood. When taking these cross-sections, they were generally taken perpendicular to the flow direction, depending on the condition of the land, in areas with bridges and culverts, where the roughness coefficient changes and according to the density of the settlement.

Table 1 Flow rate values used in stream analysis (m^3 s^{-1})

Hydrograph Peak Values			
Relapse Period	**Karakoyun**	**Cavsak**	**Sırrın**
Q_2	7.09	2.67	6.603
Q_5	20.365	10.255	19.677
Q_{10}	33.543	18.352	32.82
Q_{25}	55.630	31.382	54.123
Q_{50}	76.280	42.596	72.482
Q_{100}	100.88	54.743	92.191
Q_{500}	147.482	79.925	133.505
Q_{1000}	167.550	90.77	151.298

3.3 Study area

Şanlıurfa, located at 37° 10' 1.49" N Latitude and 38° 47' 38.11" E Longitude, is surrounded by Diyarbakır in the northeast, Mardin in the east, Adıyaman in the northwest, Gaziantep in the west, and Syria, which has the longest land border of 789 km, in the south. The province is focused within the scope of the Southeastern Anatolia Project, which was built in the Euphrates and Tigris basins, some critical basins of Türkiye, providing 28.5% of our country's water resources and making a significant contribution to the development of the country's economy. The Euphrates basin, where the province is located, is the largest in the country and has the highest annual average river flow in Türkiye (Yenigun and Ecer 2013). With an average elevation of 518 m and a surface area of 18,584 km^2, it corresponds to 3% of Türkiye's surface area.

The province is an essential place due to its geographical location—the heights of the mountains in the north decrease towards the south. Extensive plains are located in the southern half of the city. 22% of the surface area comprises mountains, 16.3% plains, and 61.7% plateaus. The surface area comprises 98.3% of the land suitable for agricultural activities. More broadly, its land use has characterized the disturbance of forest areas (0.6%), cultivated-planted areas (67.1%), and meadows-pasture areas (37.6%). Several areas indicate that they are purely natural and lack spatial and temporal areas for agriculture processes, as shown in Fig. 2.

It has a typically continental climate. Summers are long, generally dry and hot, and winters are primarily rainy and cold. Most of the precipitation is rain; the average monthly rainfall was 87.3 mm in January. It was at its lowest level in July and August, with 0.6 mm (TSMS 2023). The annual average relative humidity is 50% km, the wind blowing from the west prevails, and its average speed is 1.7 m s^{-1}. Since the temperature is very high, the evaporation rate is accordingly high, and the annual average evaporation rate is more than 1500 mm (TSMS 2023). According to TUIK (2020) data, the city has a population of 2,115,256 people, and approximately half of the population lives in the city center. Karakoyun, Sırrın, and Cavsak streams in the city center were chosen as the research area in Fig. 3.

The HEC-RAS program applied hydraulic modeling, model simulation, and floodplain mapping, bridge bottom elevation (flow elevation), bridge deck bottom elevation, bridge deck, fill elevation, and bridge width information are entered to define for design culvert components, also deal with flow characteristics (abrasiveness, pH, and velocity), sedimentation and erosion issues for the identifying flood risk parameters (Najafi and Bhattachar 2011; Şen 2020). There are twelve culverts in the Cavsak Stream, seven in the Karakoyun Stream, and fourteen in the Sırrın Stream. The accuracy of the analysis results was ensured, and on-site measurements and observations were made for all culverts in Fig. 4.

4 Results

This study aimed to carry out flood analyses of Sırrın, Cavsak, and Karakoyun streams located within the central borders of Şanlıurfa province and to determine their risk status according to their categories (agriculture, industry, urban settlement, tourism, etc.) and to be a preliminary study to determine the risky areas in economic, social and environmental

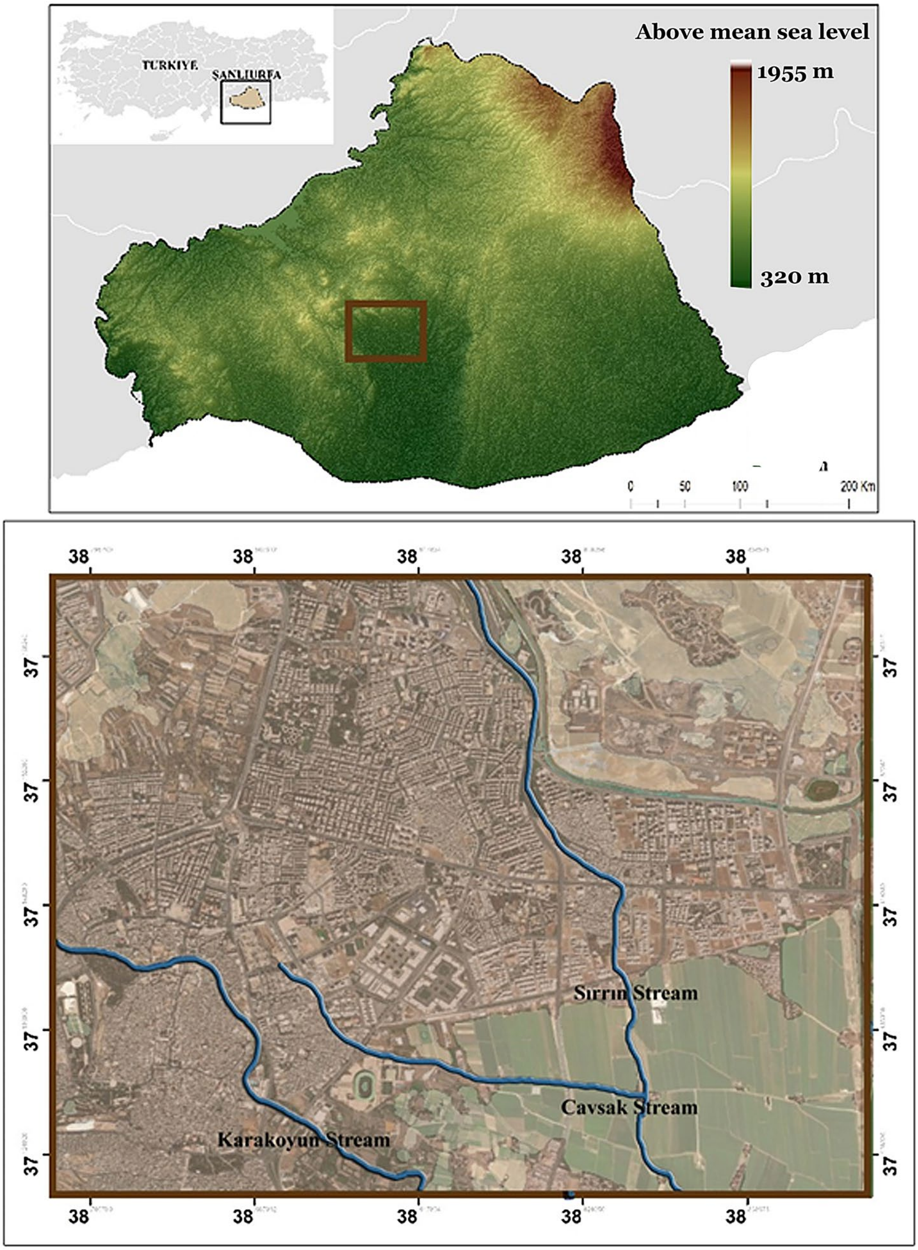

Fig. 2 Location map of the selected streams

Fig. 3 Photos of the current state of the streams a: Karakoyun, b: Sırrın, c: Cavsak

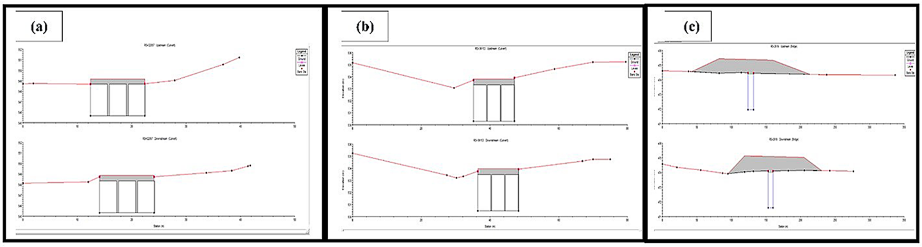

Fig. 4 Representation of culverts according to sections from different streams a: Karakoyun, b: Sırrın, c: Cavsak

terms. As a result, the study is planned to collect the necessary data for the creation of early warning systems and precaution packages by identifying low, medium, high, and very high probability flood zones for Şanlıurfa province and to form the basis for studies on this subject in Fig. 5. In Karakoyun Creek, it is seen that many sections are at risk of flooding from flood flow Q_2. It was seen that the area where the shopping center is located is hazardous due to disastrous failure resulting in uncontrolled flooding. Thus, the cross sections are inadequate for flood protection design.

The hydrological model was created with the HEC-HMS program, the hydraulic model was created with the HEC-RAS program, and flood analysis was performed. With the help of the Watershed Modeling System (WMS) program, the basin area, slope, boundaries, isohypses of the stream, land use status, and stream route were modeled. The model created in the HEC-RAS program was calibrated according to the flow and precipitation values measured in the basin area in the past years, and flood maps were created for both the mainstream route and the tributaries, taking into account the values of the rainfall in July 2005, which was heavy rainfall. As a result of the study, the flood analysis of Sırrın Stream was made, and the residential areas that may be affected by flooding were determined in Fig. 6. Also, it is estimated that there may be a flood risk starting from flood flow rate Q_{50}, mainly in the downstream sections of the Sırrın stream. Moreover, there are primarily agricultural lands in these areas.

In Cavsak Stream, it was given that there is a flood risk in sections starting from the Q_{50} flood flow rate. It was stated that two neighborhoods (Kamberiye and Sancaktar Neighborhoods) are at risk of flooding starting from the Q_{100} flow rate. Kamberiye Neighborhood is generally zoned commercial and residential and has a very crowded population density. It was termed agricultural lands on the stream route's southeast side in Fig. 7. As a result

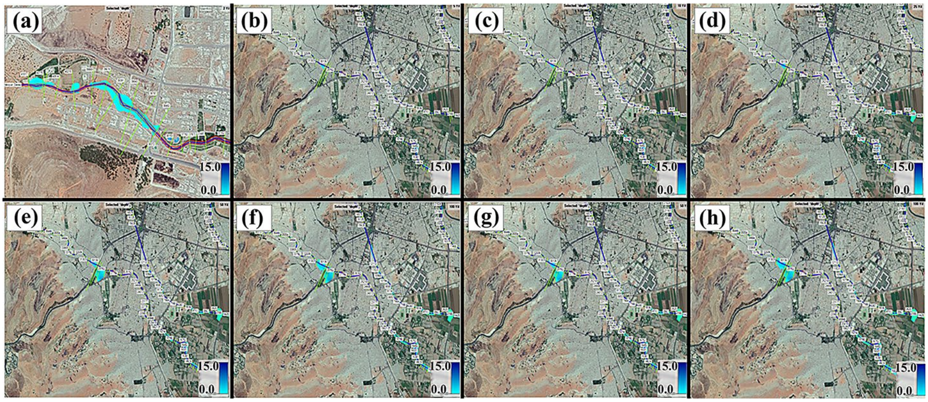

Fig. 5 Karakoyun Stream cross sections at different flood recurrence flow rates (a: Q_2, b: Q_5, c: Q_{10}, d: Q_{25}, e: Q_{50}, f: Q_{100}, g: Q_{500}, h: Q_{1000})

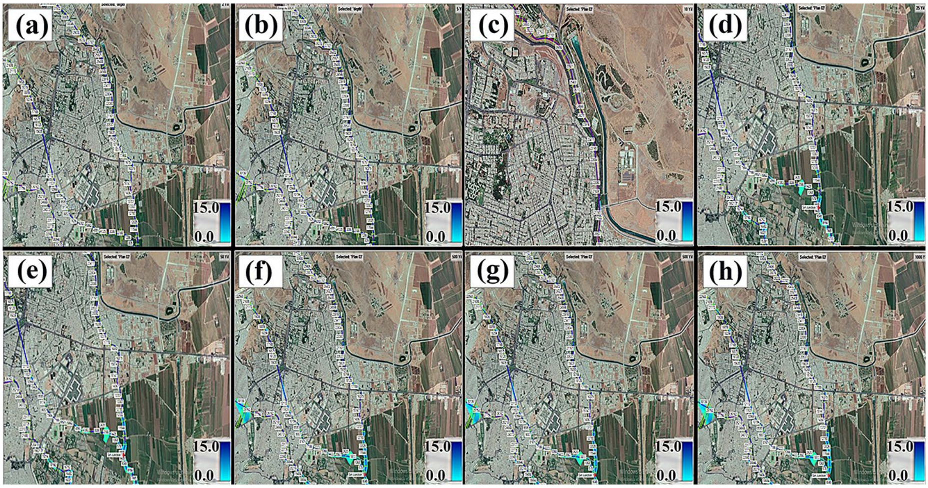

Fig. 6 Sırrın Stream cross sections at different flood recurrence flow rates (a: Q_2, b: Q_5, c: Q_{10}, d: Q_{25}, e: Q_{50}, f: Q_{100}, g: Q_{500}, h: Q_{1000})

of the analysis, the risk status of areas such as housing, industry, health, education, socio-cultural facilities, public institutions, etc. As a result of the study, areas with flood risk were identified, and it was stated that they should be studied in more detail with the multicriteria decision-making method. The generated data was transferred to the HEC-RAS program, hydraulic modeling was carried out according to the flow values with long-term flood renewal, and maps showing the flood spreading areas were created using water surface profiles.

In a variety of flood risk research, using a combination of GIS and hydraulic models, a time-invariant one-dimensional flow analysis in Arc/HEC-2 was modeled a time-invariant one-dimensional flow analysis in Arc/HEC-2 and created software that applies this analysis on top of terrain information organized in ArcGIS, a GIS program (Poussin et al. 2015;

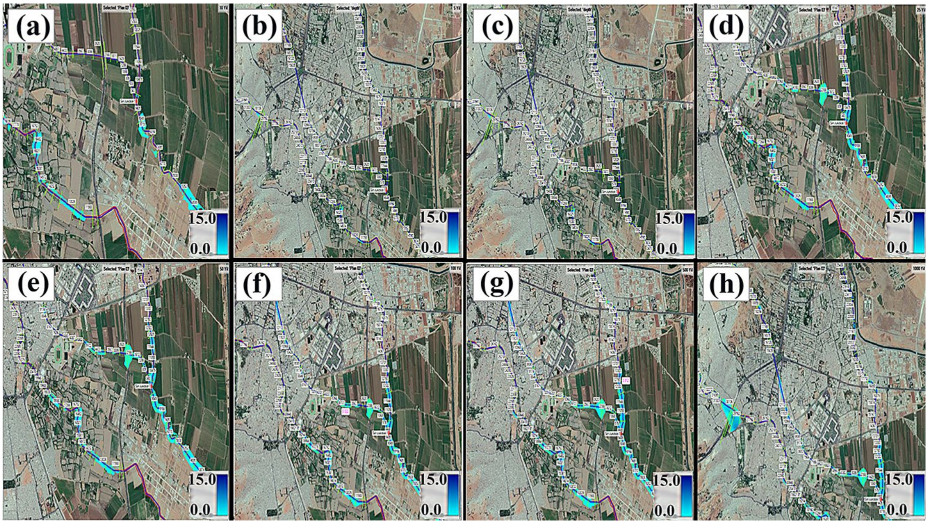

Fig. 7 Cavsak Stream cross sections at different flood recurrence flow rates (a: Q_2, b: Q_5, c: Q_{10}, d: Q_{25}, e: Q_{50}, f: Q_{100}, g: Q_{500}, h: Q_{1000})

Nkwunonwo et al. 2020). In order to determine the flood areas that may occur according to the average 100-year flood recurrence flow rate, hydraulic analysis was performed with the HEC-HMS program. In reviewing these flood models, after determining the inertial wave equation, the flood flow rate, the elevations kinematic wave, and the diffusive wave where the water levels will rise during the flood were determined with the help of the HEC-RAS program. Throughout the literature on marking the water surface elevations in ArcGIS, the flood areas were visualized in 2D, and flood risks were determined. After performing hydrological analyses with HEC-HMS, flood analysis with the HEC-RAS program was performed, and compared the analysis results with satellite images.

The fragile nature of the region against flood disasters is known. For this reason, in previous studies, flood protection structures were evaluated by examining the flood history in the area (Yenigün et al. 2016). In particular, the negative impacts of future floods in Şanlıurfa have been evaluated by taking into account the condition of the land, stream routes and capacities, hydrological characteristics, flood protection structures, urban infrastructure status, and the location of the areas selected for development by local authorities. In addition, the status of the flood control structures built by Şanlıurfa Metropolitan Municipality in the areas examined in this context was examined, and it was also evaluated whether the flood risk occurs under current conditions.

This paper has gained a unique and up-to-date quality compared to other studies in terms of precise cross-sectioning of the studied streams; all flood recurrence flows, detailed analysis of the construction in the floodplains, comprehensive evaluation of possible risk areas, and similar aspects. In the research conducted in 2021, the risk of the region, including the shopping center, was determined at the Q_{1000} flood recurrence rate in Fig. 8.

5 Discussion

Climate change represents the most devastating disasters on our planet, with interacting floods in urban areas (Isinkaralar and Isinkaralar 2023). In recent destructive flood events, twenty-one people died in the 2023 Adıyaman-Şanlıurfa flood disaster due to excessive rainfall in the region. In addition, urban uses such as residences, workplaces and parking areas, transportation, communication and energy infrastructure, vehicles, and various household items were damaged, causing severe material damage. The study has a methodological approach that can prevent material and moral losses. However, in practice, decision-makers need to consider research. Flood risk management issues in the field of urban planning have been widely covered by French and Jones (2015); Lamb et al. (2019); Kuhlicke et al. (2020); and Vitale (2023). Bridges and culverts built following a standard decision-making model within mathematical and numerical approaches to prevent flood risk have had slow and erratic results, with development not taking into account significant or radical changes over time (Vafadarnikjoo et al. 2023; Seebauer et al. 2023). Numerous research studies assert that flood risk calculations are critical in establishing flood management and prevention within this framework.

Some studies examined flood risk and its measures, which depend on the type of method and method of measurement. Botzen et al. (2019) revealed that many people take more flood-proofing measures in their homes in high-risk zones than in low-risk zones. In their context, statistical models were used to assess survey data and showed that the efficacy of dry and wet flood defenses is a significant consideration in implementing such measures. In our article, flood risk calculations were performed, and the data obtained was compared with that of other studies. The fact that the average coefficient is lower than the others does not cause negative results; it only results in a higher and more severe flood risk. Ogras and Onen (2020) investigated hydraulic structures of the Tigris River with the supercritical stream by the HEC-RAS, which defined water surface profiles of Q values (25–500) and one-dimensional floodplain analysis. Abbas et al. (2020) studied water levels using the HEC-RAS (one-dimensional and steady) model. The MRC of 0.025 provided an adequate level between the simulated and measured water levels. This work is close to our values as an acceptable match.

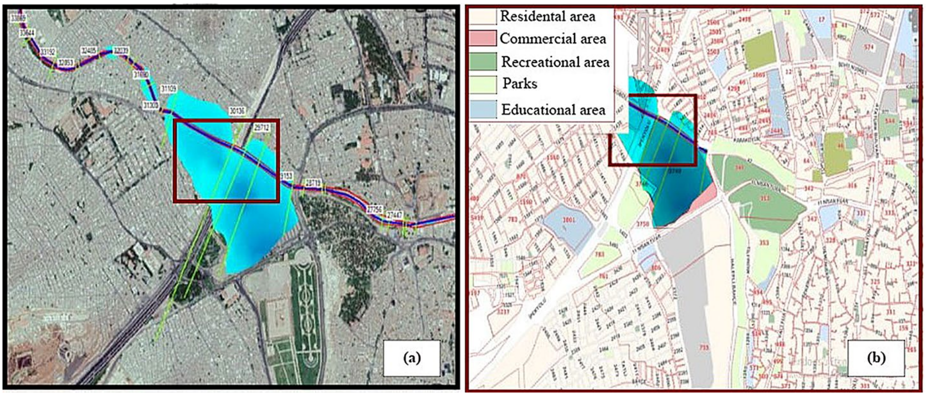

Fig. 8 (a): The region determined in the Q_{1000} flood recurrence flow rate, and (b): The urban planning zoning status of the region

The findings obtained in another study located between Al Hindiya Dam and Kufa Dam coincide with our data by Hadi et al. (2023). They calculated the MRC as 0.045 for the channel and 0.047 for floodplain roughness. Similar results were obtained by Ardıçlıoğlu and Kuriqi (2019). They found the MRC n-values wide-ranging between 0.023 and 0.055 at Sarimsakli Creek for several profiles. Shahverdi and Talebmorad (2023) performed the HEC-RAS analysis to optimize the MRC in Shahab River's main channel and floodplain, Iran. The main channel and floodplain values were 0.061, 0.057, 0.040, and 0.069, 0.059, 0.046, lower than the values estimated by the Cowan method. Many researchers have reported utilization of the HEC-RAS that plays an essential role in water engineering and can interact with several factors, including the MRC value (Vatanchi and Maghrebi 2019; Deshays et al. 2021; Norouzi and Bazargan 2022).

However, some studies have highlighted that the behavior of rainfall amount cannot be predicted and that the avoidance planning approach, disaster-sensitive planning, and smart cities are underlined for rainfall amounts exceeding the limit worldwide (Goswami et al. 2023; Vijayachandran and Singh 2023). Tamiru and Dinka (2021) reported a study on the HEC-RAS model combined with ANN for delineating flooded lands of the Baro Akobo River Basin in Ethiopia. The accuracy of the model increased considerably, and findings obtained from the ANN model were integrated into the HEC-RAS for flood depth zones. Similarly, Shah et al. (2022) explored HEC-RAS 2D simulation in the Vishwamitri River, Vadodara district, for flood mapping. Phyo et al. (2023) conducted simulated research in the Yaedashe Township of the Bago Region to assess the impact of unsteady flow by HEC-RAS simulation. This study employs the analysis results of 1D (20.78–22.02 m of floodwater depth on 45.52 km^2) and 2D (14.26–39.5 m of floodwater depth on 52.17 km^2) are very dissimilar for creating an emergency action plan (EAP). Shaikh et al. (2022) used a 2D hydrodynamic model using HEC-RAS for a flood event in 2006 in Surat City, Gujarat. Their findings indicated that water reaches a depth of 1 m in 40–50 h in a significant part of the western region, while it takes 30–40 h to reach the same depth in the northern region. The west and north zones were flooded initially and reached a depth of 1 m in approximately 40 h of arrival time. This can lead to identifying the risk zones vital for improving flood risk management and disaster preparedness. Drawing on the research performed by Stoleriu et al. (2020), El Bilali et al. (2021), Huţanu et al. (2020), Psomiadis et al. (2021), and Khouz et al. (2023), this study employs the rainfall, climatic conditions, urban dynamic data mapped and distributed to all levels were used to show the degree of flood risk. Within this literature, it is crucial to acknowledge regional environmental data when evaluating the most vulnerable to flash flood zones in urban areas.

Based on the different findings, the uncertainty has been highly presented by the HEC-RAS, suggesting that the MRC should be identified with adequate precision in order to mitigate the economic costs and human losses associated with flooding. The novelty of the current paper contributes to advancing resilience, sustainability, and community development in the context of rising flood risks due to climate change and population growth. Also, it proposes a systematic approach to automatically checking the HEC-RAS and linking it with an optimizer/uncertainty analyzer to iteratively run the HEC-RAS and the optimizer/uncertainty analyzer on hydraulic parameters in the Şanlıurfa city.

6 Conclusion

The increasingly critical issue of flooding in Şanlıurfa City is essential for urban infrastructure and land use and should be monitored continuously. It has emerged that this situation should not be ignored in current research and urban planning. Monitoring and controlling floods, evacuating, transforming, and rehabilitating risky areas, and the existence of early warning systems are essential for the subject. It should be stated that the effect of human activities is a significant factor in floods, and raising public awareness on this issue should be a primary strategy. It is necessary to investigate the population affected by the flood, possible damage and vulnerability, and response capacity with flood risk maps. To move towards a sustainable environment, taking precautions before disasters occur will prevent possible loss of life and property. However, knowing the areas with high flood risk during the preparation of urban development plans can be a handy guide when recommending construction areas. Unfortunately, on March 15, 2023, the flood was one of the most devastating floods in the city. Flooding significantly impacted Şanlıurfa; rainfall of 180–190 kg m^{-2} suddenly caused three streams to overflow through the city center. In the flood disaster, 17 people died, and 62 people were injured in the region. It was seen that people lost their lives, and many were injured during the flooding. Also, the urban economy affected almost $15 million in the region. One of the places most affected by the flood disaster, Şanlıurfa Archeology Museum, one of the largest archeology museums in Türkiye, has been damaged by approximately 65 thousand artifacts in its storage. To the best of our knowledge to make sure this never happens again, prioritizing measures are as follows: (i) a dataset needs to be collected to variables and characteristics, (ii) it can examine the costs and benefits of flood risk mitigation, (iii) several technologies can be assessed to reduce flood risk. Further research on flood management strategies could ensure the development of informed policymakers worldwide.

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Data availability The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Ethics approval All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

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References

Abbas SA, Al-Aboodi AH, Ibrahim HT (2020) Identification of Manning's coefficient using HEC-RAS model: upstream Al-Amarah barrage. Journal of Engineering, 2020, 1–7. https://doi.org/10.1155/2020/6450825

Abebe YA, Ghorbani A, Nikolic I, Vojinovic Z, Sanchez A (2019) Flood risk management in Sint Maarten–A coupled agent-based and flood modelling method. J Environ Manage 248:109317. https://doi.org/10.1016/j.jenvman.2019.109317

Afzal MA, Ali S, Nazeer A, Khan MI, Waqas MM, Aslam RA et al (2022) Flood inundation modeling by integrating HEC–RAS and satellite imagery: a case study of the Indus River Basin. Water 14(19):2984. https://doi.org/10.3390/w14192984

AL-Hussein AA, Khan S, Ncibi K, Hamdi N, Hamed Y (2022) Flood analysis using HEC-RAS and HEC-HMS: a case study of Khazir River (Middle East—Northern Iraq). Water 14(22):3779. https://doi.org/10.3390/w14223779

Alves A, Gersonius B, Kapelan Z, Vojinovic Z, Sanchez A (2019) Assessing the co-benefits of green-blue-grey infrastructure for sustainable urban flood risk management. J Environ Manage 239:244–254. https://doi.org/10.1016/j.jenvman.2019.03.036

Andor MA, Osberghaus D, Simora M (2020) Natural disasters and governmental aid: is there a charity hazard. Ecol Econ 169:106534. https://doi.org/10.1016/j.ecolecon.2019.106534

Ardıçlıoğlu M, Kuriqi A (2019) Calibration of channel roughness in intermittent rivers using HEC-RAS model: case of Sarimsakli Creek, Turkey. SN Appl Sci 1:1080. https://doi.org/10.1007/s42452-019-1141-9

Bae S, Chang H (2019) Urbanization and floods in the Seoul Metropolitan area of South Korea: what old maps tell us. Int J Disaster Risk Reduct 37:101186. https://doi.org/10.1016/j.ijdrr.2019.101186

Bharath A, Shivapur AV, Hiremath CG, Maddamsetty R (2021) Dam break analysis using HEC-RAS and HEC-GeoRAS: a case study of Hidkal dam, Karnataka state, India. Environ Challenges 5:100401. https://doi.org/10.1016/j.envc.2021.100401

Botzen WW, Kunreuther H, Czajkowski J, de Moel H (2019) Adoption of individual flood damage mitigation measures in New York City: an extension of Protection Motivation Theory. Risk Anal 39(10):2143–2159. https://doi.org/10.1111/risa.13318

Cea L, Costabile P (2022) Flood risk in urban areas: modelling, management and adaptation to climate change. Rev Hydrology 9(3):50. https://doi.org/10.3390/hydrology9030050

Chen YE, Li C, Chang CP, Zheng M (2021) Identifying the influence of natural disasters on technological innovation. Econ Anal Policy 70:22–36. https://doi.org/10.1016/j.eap.2021.01.016

Corringham TW, McCarthy J, Shulgina T, Gershunov A, Cayan DR, Ralph FM (2022) Climate change contributions to future atmospheric river flood damages in the western United States. Sci Rep 12(1):13747. https://doi.org/10.1038/s41598-022-15474-2

Costache R (2019) Flood susceptibility assessment by using bivariate statistics and machine learning models-a useful tool for flood risk management. Water Resour Manage 33(9):3239–3256. https://doi.org/10.1007/s11269-019-02301-z

Cowan WL (1956) Estimating hydraulic roughness coefficients. Agricultural Eng 37(7):473–475

Deshays R, Segovia P, Duviella E (2021) Design of a MATLAB HEC-RAS interface to test advanced control strategies on water systems. Water 13(6):763. https://doi.org/10.3390/w13060763

Disse M, Johnson TG, Leandro J, Hartmann T (2020) Exploring the relation between flood risk management and flood resilience. Water Secur 9:100059. https://doi.org/10.1016/j.wasec.2020.100059

El Bilali A, Taleb A, Boutahri I (2021) Application of HEC-RAS and HEC-LifeSim models for flood risk assessment. J Appl Water Eng Res 9(4):336–351. https://doi.org/10.1080/23249676.2021.1908183

Ferguson CR, Fenner RA (2020) The potential for natural flood management to maintain free discharge at urban drainage outfalls. J Flood Risk Manag, 13(3), e12617

French R, Jones M (2015) Culvert blockages in two Australian flood events and implications for design. Australasian J Water Resour 19(2):134–142. https://doi.org/10.1080/13241583.2016.1172693

Gallego J (2018) Natural disasters and clientelism: the case of floods and landslides in Colombia. Electoral Stud 55:73–88. https://doi.org/10.1016/j.electstud.2018.08.001

Garcia M, Juan A, Bedient P, Water (2020) 12(8), 2259. https://doi.org/10.3390/w12082259

Goswami G, Prasad RK, Kumar D (2023) Hydrodynamic flood modeling of Dikrong River in Arunachal Pradesh, India: a simplified approach using HEC-RAS 6.1. Model Earth Syst Environ 9(1):331–345. https://doi.org/10.1007/s40808-022-01507-2

Hadi ZN, Almansori NJH (2023) Estimation of manning coefficient for the section between Al-Hindiya barrage and Al-Kufa barrage utilizing HEC-RAS. Materials Today: Proceedings, 80, 2595–2601. https://doi.org/10.1016/j.matpr.2021.06.417

Hagos YG, Andualem TG, Yibeltal M, Mengie MA (2022) Flood hazard assessment and mapping using GIS integrated with multicriteria decision analysis in upper Awash River basin, Ethiopia. Appl Water Sci 12(7):148. https://doi.org/10.1007/s13201-022-01674-8

Handayani W, Chigbu UE, Rudiarto I, Putri IHS (2020) Urbanization and increasing flood risk in the Northern Coast of Central Java—Indonesia: an assessment towards better land use policy and flood management. Land 9(10):343. https://doi.org/10.3390/land9100343

Hosseinzadeh-Tabrizi A, Ghaeini-Hessaroeyeh M (2015) Coupled dam-break flow and bed load modelling using HLLC-WAF scheme. Water Sci Technol 72(7):1155–1167. https://doi.org/10.2166/wst.2015.324

Huţanu E, Mihu-Pintilie A, Urzica A, Paveluc LE, Stoleriu CC, Grozavu A (2020) Using 1D HEC-RAS modeling and LiDAR data to improve flood hazard maps accuracy: a case study from Jijia Floodplain (NE Romania). Water 12(6):1624. https://doi.org/10.3390/w12061624

Isinkaralar O, Isinkaralar K (2023) Projection of bioclimatic patterns via CMIP6 in the Southeast Region of Türkiye: a guidance for adaptation strategies for climate policy. Environ Monit Assess 195(12):1448. https://doi.org/10.1007/s10661-023-11999-9

Isinkaralar O, Isinkaralar K, Sevik H, Küçük Ö (2023) Spatial modeling the climate change risk of river basins via climate classification: a scenario-based prediction approach for Türkiye. Nat Hazards 1–18. https://doi.org/10.1007/s11069-023-06220-6

Jahangir MH, Reineh SMM, Abolghasemi M (2019) Spatial predication of flood zonation mapping in Kan River Basin, Iran, using artificial neural network algorithm. Weather Clim Extremes 25:100215. https://doi.org/10.1016/j.wace.2019.100215

Jongman B (2018) Effective adaptation to rising flood risk. Nat Commun 9(1):1986. https://doi.org/10.1038/s41467-018-04396-1

Khouz A, Trindade J, Santos PP, Oliveira SC, El Bchari F, Bougadir B et al (2023) Flood Susceptibility Assessment through statistical models and HEC-RAS analysis for sustainable management in Essaouira Province. Morocco Geosci 13(12):382. https://doi.org/10.3390/geosciences13120382

Kuhlicke C, Seebauer S, Hudson P, Begg C, Bubeck P, Dittmer C et al (2020) The behavioral turn in flood risk management, its assumptions and potential implications. Wiley Interdisciplinary Reviews: Water 7(3):e1418. https://doi.org/10.1002/wat2.1418

Kumar N, Kumar M, Sherring A, Suryavanshi S, Ahmad A, Lal D (2020) Applicability of HEC-RAS 2D and GFMS for flood extent mapping: a case study of Sangam area, Prayagraj, India. Model Earth Syst Environ 6(1):397–405. https://doi.org/10.1007/s40808-019-00687-8

Kürkçüoğlu AC, Yenigün K, Yazgan MS (2013) The justinian system: one of the oldest flood control facilities in the world. Water Sci Technology: Water Supply 13(3):683–691. https://doi.org/10.2166/ws.2013.015

Lamb R, Garside P, Pant R, Hall JW (2019) A probabilistic model of the economic risk to Britain's railway network from bridge scour during floods. Risk Anal 39(11):2457–2478. https://doi.org/10.1111/risa.13370

Li H, Xu E, Zhang H (2021) Examining the coupling relationship between urbanization and natural disasters: a case study of the Pearl River Delta, China. Int J Disaster risk Reduct 55:102057. https://doi.org/10.1016/j.ijdrr.2021.102057

Liu Y, Huang X, Yang H (2022) An integrated approach to investigate the coupling coordination between urbanization and flood disasters in China. J Clean Prod 375:134191. https://doi.org/10.1016/j.jclepro.2022.134191

Madhuri R, Raja YS, Raju KS, Punith BS, Manoj K (2021) Urban flood risk analysis of buildings using HEC-RAS 2D in climate change framework. H2Open J 4(1):262–275. https://doi.org/10.2166/h2oj.2021.111

Mahmood S, Rahman AU, Shaw R (2019) Spatial appraisal of flood risk assessment and evaluation using integrated hydro-probabilistic approach in Panjkora River Basin. Pakistan Environ Monit Assess 191:573. https://doi.org/10.1007/s10661-019-7746-z

Manandhar B, Cui S, Wang L, Shrestha S (2023) Urban Flood Hazard Assessment and Management practices in South Asia: a review. Land 12(3):627. https://doi.org/10.3390/land12030627

Mukherjee F, Singh D (2020) Detecting flood prone areas in Harris County: a GIS based analysis. GeoJournal 85(3):647–663. https://doi.org/10.1007/s10708-019-09984-2

Najafi M, Bhattachar DV (2011) Development of a culvert inventory and inspection framework for asset management of road structures. J King Saud University-Science 23(3):243–254. https://doi.org/10.1016/j.jksus.2010.11.001

Namara WG, Damisse TA, Tufa FG (2022) Application of HEC-RAS and HEC-GeoRAS model for flood inundation mapping, the case of awash bello flood plain, upper Awash River Basin, Oromiya regional state, Ethiopia. Model Earth Syst Environ 8(2):1449–1460

Nkwunonwo UC, Whitworth M, Baily B (2020) A review of the current status of flood modelling for urban flood risk management in the developing countries. Sci Afr 7:e00269. https://doi.org/10.1016/j.sciaf.2020.e00269

Nordbeck R, Steurer R, Löschner L (2019) The future orientation of Austria's flood policies: from flood control to anticipatory flood risk management. J Environ Planning Manage 62(11):1864–1885. https://doi.org/10.1080/09640568.2018.1515731

Norouzi H, Bazargan J (2022) Calculation of water depth during flood in rivers using linear muskingum method and particle swarm optimization (PSO) algorithm. Water Resour Manage 36(11):4343–4361. https://doi.org/10.1007/s11269-022-03257-3

Ogras S, Onen F (2020) Flood analysis with HEC-RAS: a case study of Tigris River. Adv Civil Eng 2020(6131982). https://doi.org/10.1155/2020/6131982

Peng J, Zhang J (2022) Urban flooding risk assessment based on GIS-game theory combination weight: a case study of Zhengzhou City. Int J Disaster risk Reduct 77:103080. https://doi.org/10.1016/j.ijdrr.2022.103080

Phyo AP, Yabar H, Richards D (2023) Managing dam breach and flood inundation by HEC-RAS modeling and GIS mapping for disaster risk management. Case Stud Chem Environ Eng 8:100487. https://doi.org/10.1016/j.cscee.2023.100487

Poussin JK, Botzen WW, Aerts JC (2015) Effectiveness of flood damage mitigation measures: empirical evidence from French flood disasters. Glob Environ Change 31:74–84. https://doi.org/10.1016/j.gloenvcha.2014.12.007

Pralle S (2019) Drawing lines: FEMA and the politics of mapping flood zones. Clim Change 152(2):227–237. https://doi.org/10.1007/s10584-018-2287-y

Psomiadis E, Tomanis L, Kavvadias A, Soulis KX, Charizopoulos N, Michas S (2021) Potential dam breach analysis and flood wave risk assessment using HEC-RAS and remote sensing data: a multicriteria approach. Water 13(3):364. https://doi.org/10.3390/w13030364

Rehman J, Sohaib O, Asif M, Pradhan B (2019) Applying systems thinking to flood disaster management for a sustainable development. Int J Disaster risk Reduct 36:101101. https://doi.org/10.1016/j.ijdrr.2019.101101

Seebauer S, Thaler T, Hanger-Kopp S, Schinko T (2023) How path dependency manifests in flood risk management: observations from four decades in the Ennstal and Aist catchments in Austria. Reg Envriron Chang 23(1):31. https://doi.org/10.1007/s10113-023-02029-y

Şen Z (2020) Water structures and climate change impact: a review. Water Resour Manage 34(13):4197–4216. https://doi.org/10.1007/s11269-020-02665-7

Shah Z, Saraswat A, Samal DR, Patel D (2022) A single interface for rainfall-runoff simulation and flood assessment—a case of new capability of HEC-RAS for flood assessment and management. Arab J Geosci 15(18):1526. https://doi.org/10.1007/s12517-022-10721-2

Shahverdi K, Talebmorad H (2023) Automating HEC-RAS and linking with particle Swarm Optimizer to Calibrate Manning's roughness coefficient. Water Resour Manage 37(2):975–993. https://doi.org/10.1007/s11269-022-03422-8

Stoleriu CC, Urzica A, Mihu-Pintilie A (2020) Improving flood risk map accuracy using high-density LiDAR data and the HEC-RAS river analysis system: a case study from north-eastern Romania. J Flood Risk Manag 13:e12572. https://doi.org/10.1111/jfr3.12572

Tamiru H, Dinka MO (2021) Application of ANN and HEC-RAS model for flood inundation mapping in lower Baro Akobo River Basin, Ethiopia. J Hydrology: Reg Stud 36:100855. https://doi.org/10.1016/j.ejrh.2021.100855

Theodosopoulou Z, Kourtis IM, Bellos V, Apostolopoulos K, Potsiou C, Tsihrintzis VA (2022) A fast Data-Driven Tool for Flood Risk Assessment in Urban Areas. Hydrology 9(8):147. https://doi.org/10.3390/hydrology9080147

TSMS (2023) Turkish State Meteorological Service of Ministry of Agriculture and Forestry. https://www.mgm.gov.tr/veridegerlendirme/ilveilceleristatistik.aspx?k=undefined&m=SANLIURFA

TUIK (2020) Address based population registration system results. Available online: http://www.tuik.gov.tr/PreTablo.do?alt_id=1059 (Accessed on 20 June 2022)

Tyler J, Sadiq AA, Noonan DS (2019) A review of the community flood risk management literature in the USA: lessons for improving community resilience to floods. Nat Hazards 96:1223–1248. https://doi.org/10.1007/s11069-019-03606-3

Vafadarnikjoo A, Chalvatzis K, Botelho T, Bamford D (2023) A stratified decision-making model for long-term planning: application in flood risk management in Scotland. Omega 116:102803. https://doi.org/10.1016/j.omega.2022.102803

Vatanchi SM, Maghrebi MF (2019) Uncertainty in rating-curves due to manning roughness coefficient. Water Resour Manage 33(15):5153–5167. https://doi.org/10.1007/s11269-019-02421-6

Vijayachandran L, Singh AP (2023) Flood risk assessment in the Karamana river basin, Kerala, using HEC-RAS. Environ Monit Assess 195(8):922. https://doi.org/10.1007/s10661-023-11450-z
Vitale C (2023) Understanding the shift toward a risk-based approach in flood risk management, a comparative case study of three Italian rivers. Environ Sci Policy 146:13–23. https://doi.org/10.1016/j.envsci.2023.04.015
Vojtek M, Petroselli A, Vojteková J, Asgharinia S (2019) Flood inundation mapping in small and ungauged basins: sensitivity analysis using the EBA4SUB and HEC-RAS modeling approach. Hydrol Res 50(4):1002–1019. https://doi.org/10.2166/nh.2019.163
Waghwala RK, Agnihotri PG (2019) Flood risk assessment and resilience strategies for flood risk management: a case study of Surat City. Int J Disaster Risk Reduct 40:101155. https://doi.org/10.1016/j.ijdrr.2019.101155
Waldon MG (2004) Estimation of average stream velocity. J Hydraul Eng 130(11):1119–1122. https://doi.org/10.1061/(ASCE)0733-9429(2004)130:11(1119)
Wallemacq P, Below R, McClean D (2018) Economic losses, poverty & disasters: 1998–2017. United Nations Office for Disaster Risk Reduction
Yenigun K, Ecer R (2013) Overlay mapping trend analysis technique and its application in Euphrates Basin, Turkey. Meteorol Appl 20(4):427–438. https://doi.org/10.1002/met.1304
Yenigün K, Gerger R, Gerger E (2016) Evaluation of Floods in the Historical Process in Şanlıurfa Specific, 4th National Flood Symposium, Recep Tayyip Erdoğan University, Proceedings Book, 429–446, 23–25 November, Rize
Zeleňáková M, Fijko R, Labant S, Weiss E, Markovič G, Weiss R (2019) Flood risk modelling of the Slatvinec stream in Kružlov village. Slovakia J Clean Prod 212:109–118. https://doi.org/10.1016/j.jclepro.2018.12.008
Zimmermann A (2010) Flow resistance in steep streams: an experimental study. Water Resour Res 46(9). https://doi.org/10.1029/2009WR007913

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