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# Flood risk modelling using HEC-RAS and GIS in the semi-urban watershed of Oued Ziad (Constantine, North-Eastern Algeria)

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**Abstract**

The study of flood risk in Algerian cities has become essential given the multiple issues at stake (urbanization, urban sprawl, easements, infrastructure, soil structure, etc.), which constitute vulnerable elements, as well as their frequency and repetition in time and space. This has become a problem for the city and the urban environment, particularly in large metropolises such as Constantine. The watershed of Oued Ziad located in the northwestern part of the city of Constantine has experienced exceptional flooding, causing loss of life and property in the Jebli Ahmed agglomeration in the Hamma Bouziane township. The main objective of this research is to identify the factors aggravating the risk of flooding in the Oued Ziad watershed, to analyze the frequency of maximum daily rainfall to determine peak flows for different return periods of 10, 20, 50, 100 and 1000 years, and to map the extent of the flood hazard in the Oued Ziad watershed for a centennial flow, using geographic information systems and HecRas software. The simulation results show the overflow of Oued Ziad on national road N°27, affecting a part of the agglomeration located downstream by a centennial peak flow equal to 50. 98 m3/s and a water height exceeding 3 m, which confirms the extent of the area exposed to risk during the flood that occurred on 19/9/2018. The field survey shows that several anthropic factors increase the risk of flooding while the capacity of the existing hydraulic structures is insufficient to evacuate water during floods, which requires the development of this watercourse and its banks to protect the population and its property from the risk of flooding and to reduce the impact on the city's environment and socio-economic activities.
**Keywords:** *Constantine, Flood risk, hydrological modelling, geographic information system, Hec-Ras, Oued Ziad watershed*

## Introduction

Natural hazards constitute a real environmental problem, threatening people and their property, the environment, and infrastructure. Among natural hazards, floods constitute one of the world's worst natural disasters causing significant human, material, and economic losses. Over the last decade, there have been multiple investigations carried out utilizing spatial analysis to evaluate flood and sedimentation management in large geographical areas. (Rai and Mohan, 2014; Mătreaţă et al., 2016; Grecu, 2016; Grecu et al., 2017; Costache et al., 2020; Jalilzadeh and Behzadi, 2020; Nkwunonwo et al., 2020; Ongdas et al., 2020; Tegenie and Berhe, 2021; Abdelshafy and Mostafa, 2021; Xafoulis et al, 2022), these extreme hydro-climatic events due essentially to the complex interaction and concomitance of several topographical, geological, hydrological and meteorological factors, are often intensified by climate change which increases their frequency and repetition in time and space (Lasri 2019; Prăvălie and Costache, 2014). The risk of flooding is not a characteristic of the urban environment. High population density and soil impermeabilization increase the probability of flooding due to urban runoff, especially in areas with steep slopes (Nkwunonwo et al., 2020). In general, flooding is limited to the overflow of water from river beds. In the case of cities, flooding includes the amount of water that appears in public spaces, including water resulting from non-functioning sewage systems.

Flooding has become one of the most frequent and devastating natural disasters in Algeria (Derdour et al., 2017), the country's northern territories being highly threatened by this phenomenon. Indeed, the main physical features as well as the natural characteristics of these territories (aggressive climate, type of fragile plant cover, soil sealing, nature of the hydrographic network (shape, density), tend to favour torrential flows (Grecu, 2018a), which induces the overflowing of wadi beds, thus constituting a major constraint for economic and social development, by consequence: loss of human life, destruction of infrastructures (bridges, roads), destruction of housing and agricultural areas.

The study of flood risk in North-Eastern Algeria has become a priority in the context of climate change and the recurrence (frequency and repetition) of extreme events. The high concentration of the population in northern Algeria, which is experiencing accelerated and often poorly controlled urbanization, has led to the establishment of activities in flood-prone areas, reducing the permeability of the soil surface to infiltration, and consequently the formation of flash floods (Gao et al., 2021). This problem has become a serious concern for decision-makers and city managers. Intense rainfall is the main factor in the formation of flash floods, occurring within a short period (Buta et al., 2017). Several regions of the country are regularly threatened by these floods, whose effects are often intensified by anarchic urbanization involving the occupation of flooded land and even wadi banks.

The city of Constantine was severely affected by flooding, including the historic flooding of the Djebli Ahmed agglomeration on 19/09/2018, mainly due to the overflowing of the Oued Ziad watercourse following intense rainfall, causing severe damage to the population (the death of two people, and 11 others injured), and to material assets (many cars were swept away by the flooding of the wadi), as well as to infrastructures (blocked roads, disruption of economic activity) (Fig.1) (Bekhira et al., 2019). During this exceptional downpour, the rain gauge at the Hamma Bouziane station, which is the closest to Oued Ziad, recorded 33.5 mm in just 40 min, resulting in a very high flow rate of 60 m3/s and an intensity equal to 139. 6 l/s/h according to the National Agency for Hydraulic Resources (ANRH), this strong flow collected several tree trunks and blocks and deposited them in the downstream section, where they blocked the culvert and the water overflowed on the national road 27 (Fig.1). This event underlines the importance of studying flood risk in small torrential urban catchments.

The present work aims to highlight the role of torrential precipitation in the flooding of an area subject to slope runoff, by i) Identifying the factors triggering the risk of flooding in the Oued Ziad watershed, which has already been affected by a historical flood of the unknown return period. ii) Hydrological modelling of flood risk to determine the extent of the hazard and the height of water (Uca et al., 2022), also to protect people, their property, and infrastructure from the risk, and for better management and prevention of flood risk in the city by:

- The analysis of the hydro-morphometric characteristics of the watershed using geographic information systems.
- Statistical analysis of maximum daily rainfall using Hyfran plus software to determine peak flows for different return periods (10, 20, 50, 100, and 1000 years), and analysis of short-duration rainfall to determine the return period of the historic flood that has already occurred in the agglomeration located downstream of the watershed.
- Hydrological modelling of the flood hazard using Hec-Ras software, to determine water levels during floods.
- The autumn flood on 19/09/2018 is used to validate the simulation results, which serve as a decision-support document for city managers and local authorities, to protect this watercourse from flooding and Presenting a methodology for the strategic management of floods to mitigate their damage in areas invaded by human activity by calibrating it and stabilizing its banks (Bilașco et al., 2022).

## Study area

Geographically, the Oued Ziad watershed is part of the Kebir Rhumel watershed (Benabbas,2006), a tributary of Oued Rhumel with a surface area of 12.02 km$^2$ and a perimeter of 19.47 km, drained mainly by Oued Ziad with a length of 7.11 km, it is a mountainous watershed, originating from the Djebel El Wahch mountains, a mountainous area marked by a rugged relief varying between 350 and 980 meters characterized by steep to medium slopes. Oued Ziad crosses National Road N° 27, national road N° 03, and the urban limits of the Bekira agglomeration and the Constantine-Skikda railroad, it flows into Oued Rhumel downstream, characterized by a semi-arid Mediterranean climate (cold winters and hot, dry summers).

**Figure 1. The exceptional flooding of the township Djebli Ahmed caused by the overflow of Oued Ziad, photos taken by the civil protection of Constantine on 19/09/2018**

Oued Ziad is administratively located in the north-western part of the city of Constantine, in the Djebli-Ahmed agglomeration, commonly known as "El-Cantoli", which lies between the administrative boundaries of the Hamma-Bouziane municipality and the municipality of Constantine. Over half of the catchment area is built-up (Fig.2).

## Methodology

The hydraulic efficiency of different adaptation strategies was evaluated by utilizing a simplified two-dimensional flow model. This model was developed in HEC RAS Hydrologic Engineering Center River Analysis System version 6 0 by the US Army Corps of Engineers (Kashfy et al., 2021). The fundamental concept underlying the utilized modelling approach is that rainwater quantities usually gather over the urban landscape and eventually flow into the nearby canal system; a physically based model for rainfall runoff HEC RAS made its debut in 1995 and since then it has undergone validation through numerous case studies in similar settings (Yalcin, 2020). Due to the presence of local data, the entire configuration of the employed model relies on open access input data which includes freely available topographical and hydro meteorological information. The research methodology is based on 3 stages:

The first step is to study the physical and hydro-morphometric characteristics of the watershed. Indeed, knowledge of the physical characteristics of the watershed enables the determination of its morphometric parameters, which form the basic foundation for all hydrological studies (Grecu, 2018b). To process this part of the study, we used a 10 m resolution digital elevation model obtained by digitizing the contour lines of the 1:25,000 scale topographic map produced by the National Institute of Cartography and Remote Sensing (INCT) in 2006 and processed using ArcMap 10.8 software to extract the various slope, hypsometric and hydrographic network maps to calculate the morphometric parameters of the watershed. The second step is to carry out a statistical analysis of flooding. For this, we used observation data from the National Hydraulic Resources Agency (ANRH) at the station closest to our watershed, Hamma Bouziane (Table. 1), and maximum daily rainfall data over 51 years (1968-2021).

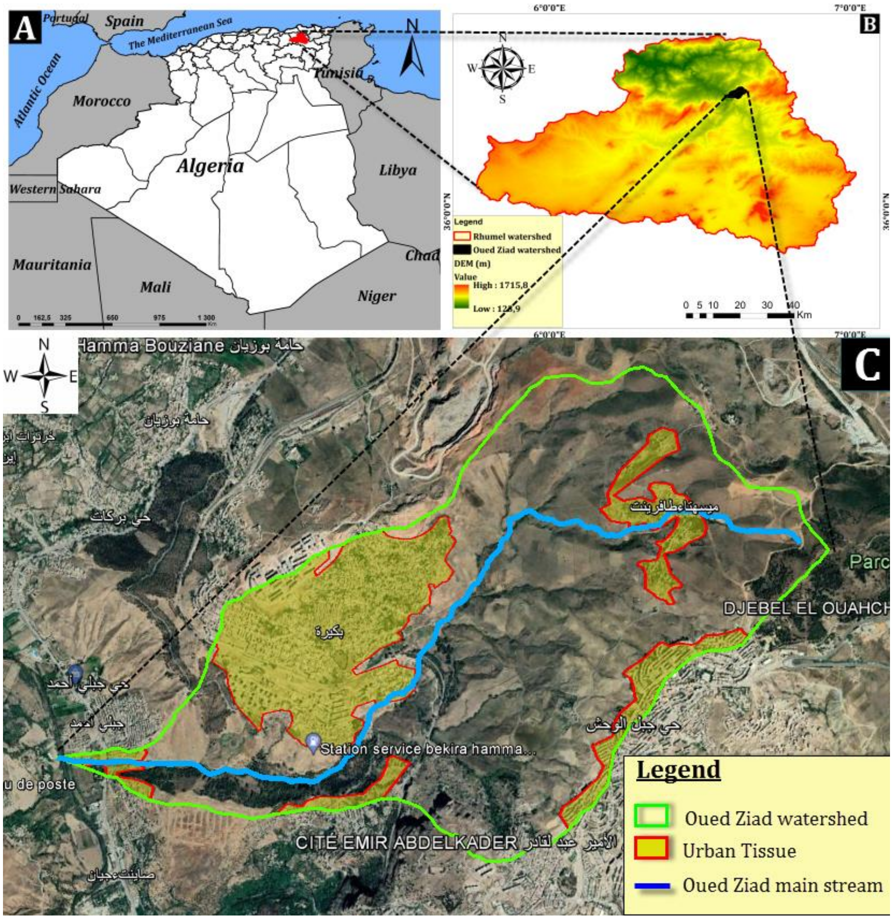


**Figure 2. Geographical location of the study area: A) Location in Algeria, B) Location in Oued Rhumel Watershed, C) Google-Earth location of the Oued Ziad watershed**

**Table 1. Characteristics of the Hamma Bouziane rainfall station**

| Station | Code | Longitude (X) | Latitude (Y) | Altitude (Z) | Years of observation | Average annual rainfall (mm) |
|---|---|---|---|---|---|---|
| Hamma Bouziane | 10-06-03 | 848.5 | 352.8 | 460 | 51 years | 528 |

*Source: national water resources agency*

For rainfall adjustment, we used HYFRAN Plus software. HYFRAN Plus is a statistical data analysis program that can be used to fit a large number of statistical distributions to a series of data observations and to check hypotheses of independence, homogeneity, and stationarity. It has been designed for frequency analysis in hydrology, especially for extreme events, or for flows for each return period recorded.

We used the Normal, Log-Normal, and Gumbel laws to analyze flood frequency. Then, we calculated the Intensity, Duration, and Frequency (IDF) curve.

IDF curves represent the evolution of rainfall intensity as a function of duration and frequency, expressed in return periods. The development of IDF curves is an extremely important tool in flood risk management and prevention. They help us to design hydraulic protection structures.

The intensity duration frequency relationship is given by the formula: $I(t,T) = a(T)/t^b$

I: intensity mm / h

a (T): maximum intensity in mm/h for a rainfall return period T

b: Montana coefficient

According to the National Hydraulic Resources Agency (ANRH), the Montana coefficient for El Hamma station is equal to 0.63. We then proceed to determine short-duration rainfall, time of concentration and peak flows for the various return periods using empirical formulas.

The third stage is devoted to the hydrological modelling of peak flows using HEC RAS (Hydrological Engineering Centers - River Analysis System) software, designed by the US Corporation Engineers Hydraulic Engineering Centre to model river flow (Brunner, 2016). This program calculates water level and velocity in rivers and builds one- or two-dimensional models to simulate water movement, whether in a stable or unstable state, including sediment transport modelling (Zellou and Rahali, 2016; AL-Hussein et al., 2022).

To generate the flood hazard map, we used the topographic survey (Sunilkumar and Varghese, 2017; Thapa et al., 2020) of Oued Ziad, obtained from the hydro project East engineering company of Constantine. The data required for this hydraulic modelling are the flows resulting from the hydrological study and the geometry of the watercourse. Wadi modelling is based on cross-sections, as well as longitudinal slope and bed and bank roughness at the various calculation points.

The integration of HEC-RAS (Hydrologic Engineering Centers River Analysis System) and GIS (Geographic Information System) technologies to obtain scientifically derived information has been effective in the simulation, identification, and analysis of flood events in a geospatial environment (Yerramilli, 2012; Lasri, 2019; Tegenie and Berhe, 2021; Awad et al., 2022).

## Results

**Determination of watershed physical characteristics and morphometric parameters**

The study of the physical characteristics (slope, hypsometry, hydrographic network) of the Oued Ziad watershed is essential for the calculation of the morphometric parameters required for our hydrological study, as well as for the study of river dynamics (Benabbas et al., 2011; Grecu et al., 2021).

The study of the slope is fundamental to any hydrological study, it enables us to determine the type and characteristics of runoff, the type of surface runoff, and the areas affected by flood risk.

According to the slope map (Figure. 3), our terrain is dominated by steep slopes ranging from 12% to 25%, the steep slope that dominates the watershed accelerates flow velocity, reducing the time of concentration (table. 2).

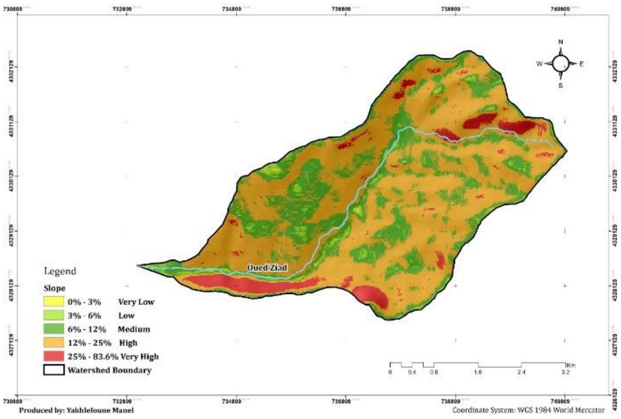


**Figure 3. Slope map**

Basin morphology is an essential element. It enables us to determine the areas likely to be affected by flooding and therefore to combat this risk. The longitudinal profile is traced using the Oued Ziad topographic survey and is presented by the altitude and length of the watercourse.

**Table 2: Slope Classes and area percentage**

| Slope classes | Area ($Km^2$) | Area (%) |
|---|---|---|
| 0% - 3% | 0.59 | 0.07 |
| 3% - 6% | 2.02 | 0.24 |
| 6% - 12% | 17.97 | 2.16 |
| 12% - 25% | 68.97 | 8.29 |
| 25% - 83.6% | 10.44 | 1.25 |
| Total | 12.02 | 100 |

It can include major infrastructures (railroads, dams) and various tributaries. From the longitudinal profile below (Figure. 4), we can see that there is a variation in slopes; the further north-east we go, the steeper the slopes (corresponding to areas of high relief). The further south we go, the steeper the slopes (corresponding to the watercourse).

Relief is one of the physical characteristics of the watershed, defined as the variation in altitude; these variations influence runoff, precipitation, vegetation, etc. To characterize the relief of the study area, we produced a hypsometric map (Figure. 5), then we calculated the distribution of the watershed surface according to the altitude, using Arcmap 10.8 to produce the hypsometric curve.

The relief of the Oued Ziad watershed is too rugged (Benabbas, 2006), with altitudes ranging from 350 m to 980 m and a relatively steep slope.

The hypsometric curve in (Figure. 6) provides a synthetic view of the slope of the watershed, hence its relief. This curve represents the distribution of the watershed's surface area as a function of its altitude. The results are detailed in (table 3).

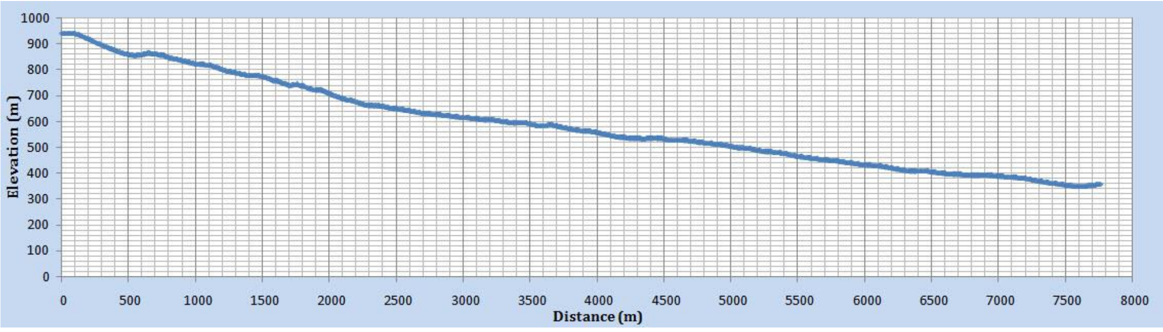


**Figure 4. Longitudinal profile of Oued Ziad**

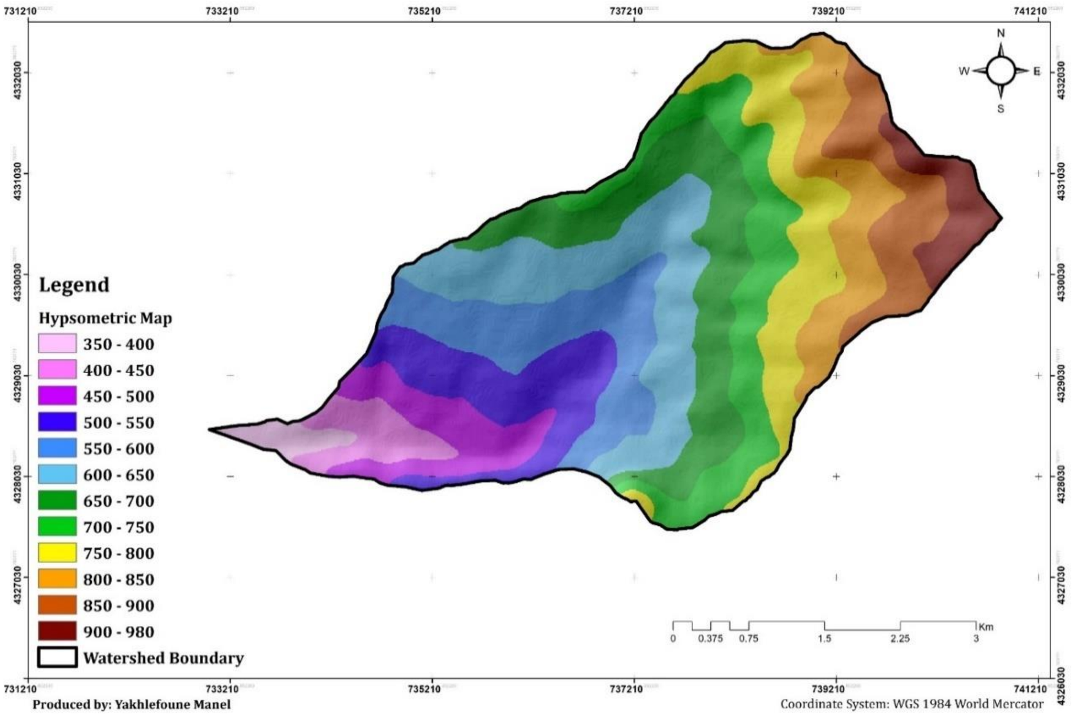


**Figure 5. The hypsometric map of the Oued Ziad watershed**

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**Table 3: Hypsometric characteristics of the Oued Ziad watershed**

| Elevation (m) | Area between curves | | Cumulative areas | |
|---|---|---|---|---|
| | Km² | % | Km² | % |
| 350 – 450 | 0,58 | 4,83 | 0,580 | 4,83 |
| 450 – 550 | 1,87 | 15,58 | 2,450 | 20,41 |
| 550 – 650 | 3,1117 | 25,93 | 5,562 | 46,34 |
| 650 – 750 | 3,0153 | 25,12 | 8,577 | 71,46 |
| 750 – 850 | 2,26 | 18,83 | 10,837 | 90,29 |
| 850 – 950 | 1,113 | 9,27 | 11,950 | 99,57 |
| 950 - 980 | 0,052 | 0,43 | 12,002 | 100,00 |
| | 12.02 | 100 | | |

This table shows the percentage of accumulated surface area above a certain altitude.

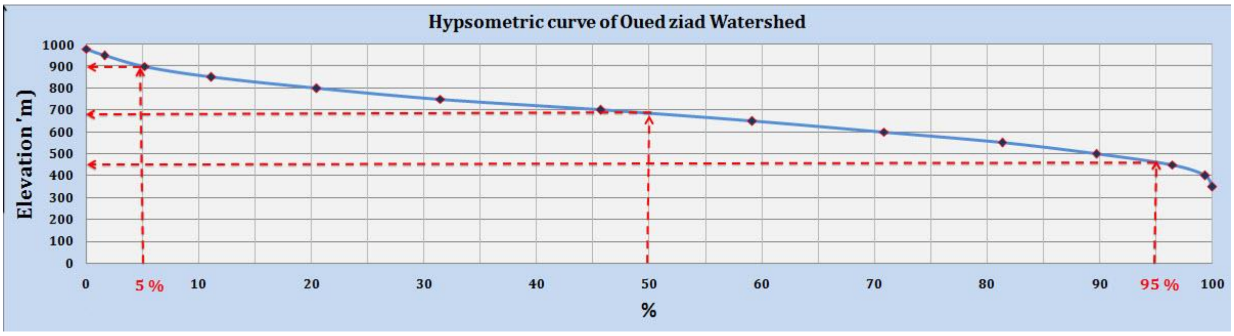


**Figure 6. The hypsometric curve of the Oued Ziad watershed**

The Oued Ziad watershed is characterized by a well-developed hydrographic network (Figure. 7), with an average drainage density of 2.43 km/km$^2$. Its main watercourse (Oued Ziad) is torrential, with an estimated length of 7.11 km, and starts flowing at an altitude of 980 m, reaching its outlet at an altitude of 350 m. The main direction of the watercourse is North-East to South-West upstream and becomes East-West downstream, the watercourse is not very sinuous and seems to follow segments of linear accidents.

The physical characteristics of the Oued Ziad watershed have enabled us to calculate its morphometric parameters (Table. 4), which help us to understand its behaviour and hydrological response, as well as the factors that aggravate hydrological risks.

### Concentration-time calculation

The time of concentration (Tc) is defined as the time required for the raindrop falling at the furthest point in the watershed to reach the stream outlet; based on the physical characteristics of the watershed, we calculated the time of concentration using various empirical formulas that are adapted to the characteristics of our watershed (Ventura's formula, Turraza's formula, Passini's formula and Giandotti's formula), then calculated the average of the values obtained (Table. 5).

### Statistical analysis of rainfall data

Statistical analysis of hydrological data aims to determine the extent of extreme events in terms of their frequency of occurrence, using probability laws (Zegait et al., 2022). The analysis of maximum daily rainfall is necessary for estimating peak flood discharges, and we used the most recent maximum daily rainfall ANRH data from the Hamma Bouziane station for the entire observation period (1968-2021), which is long enough to carry out our study.

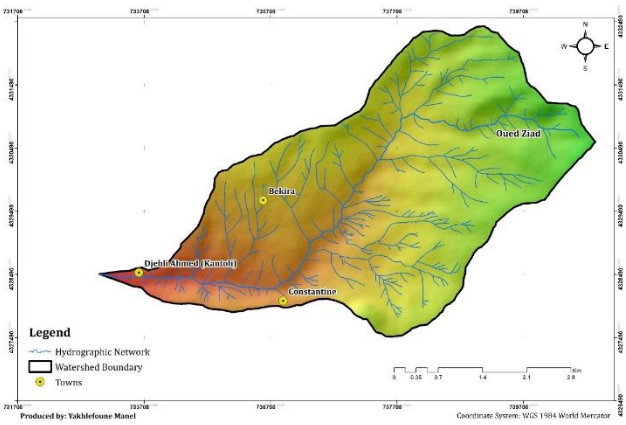


**Figure 7. Hydrographic network of the Oued Ziad watershed**

**Table 4: Morphometric characteristics of the Oued Ziad watershed**

| Morphometric parameters | | Units | Oued Ziad watershed |
|---|---|---|---|
| Area (A) | | $Km^2$ | 12.02 |
| Perimeter (P) | | Km | 19.46 |
| Main Talweg Length (L) | | Km | 7.11 |
| Compactness index (the GRAVILIUS capacity coefficient) | | / | 1.58 |
| Equivalent Rectangle | Length (L) | Km | 8.37 |
| | Width (W) | Km | 1.43 |
| Elevation Characteristics | elevation at 5% | m | 900 |
| | elevationat 95% | m | 455 |
| | Maximum elevation ($H_{max}$) | m | 980 |
| | Minimum elevation ($H_{min}$) | m | 350 |
| | Average elevation | m | 667 |
| Overall slope index (Ig) | | m/Km | 53.76 |
| Useful height difference (Du) | | m | 450 |
| Specific height difference (Ds) | | m | 186.4 |
| Watershed relief (R) | | / | Relief Fort |
| Drainage density (Dd) | | $Km/Km^2$ | 2.43 |

**Table 5: Result of concentration time calculation**

| Empirical formulas | Giandotti | Turazza | Passini | Ventura | Mean |
|---|---|---|---|---|---|
| Equa-tions | $Tc = \frac{4\sqrt{A} + 1.5L}{0.8\sqrt{Hmedian - Hmin}}$ Where A: Area ($km^2$) L: length of the equivalent Rectangle (m) | $Tc = 0.108\frac{\sqrt[3]{A \times L}}{\sqrt{P}}$ Where A: Area (Ha) L: Main Talweg Length (m) S: Slope (m/m) | $Tc = 0.108 \times \left(\frac{(A \times L)^{1/3}}{S^{0.5}}\right)$ Where A: Area ($km^2$) L: Main Talweg Length (km) S: Slope (m/m) | $Tc = 0.13\sqrt{\frac{A}{S}}$ Where A: Area ($km^2$) S: Slope (m/m) | / |
| Tc(hour) | 1.44 | 1.5 | 1.94 | 1.59 | 1.62 |

The value adopted is the result closest to the averages of the results of the four formulas used. The concentration time is 1.59 h.

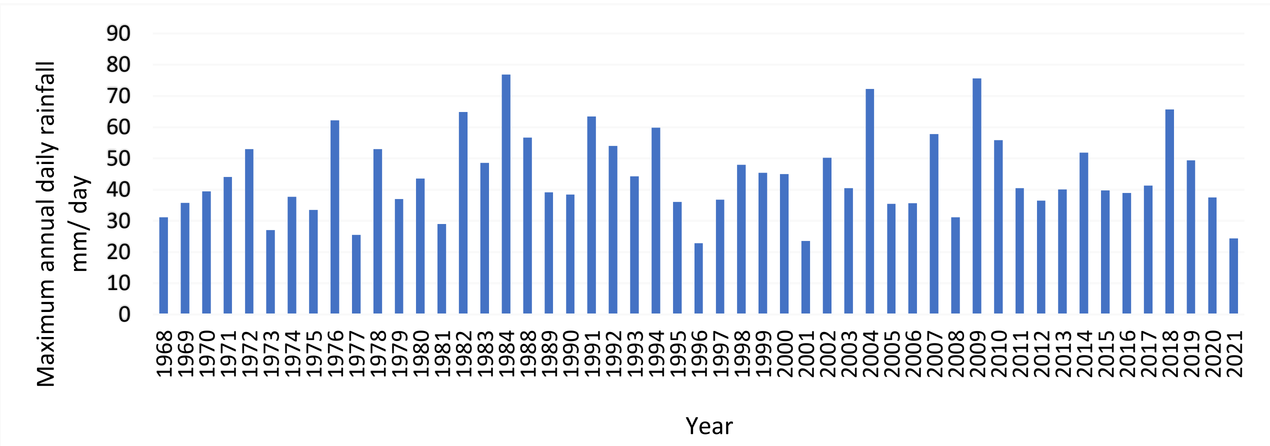


**Figure 8. Maximum annual daily rainfall of Hamma Bouaziane station from 1968 to 2021**

The highest value recorded of the maximum daily rainfall is equal to 76.9 mm/day, for the hydrological year 1984, and the lowest value recorded of the maximum daily rainfall is equal to 22.8 mm/day, for the hydrological year 1996 (Figure. 8).

**Statistical adjustment to the Gumbel probability law**

Algeria is subject to a highly unpredictable and irregular climate; however, the choice of an asymmetrical statistical law is essential for the statistical analysis of maximum daily rainfall. To obtain more accurate results, we adjusted the series of observations of maximum daily rainfall at the rainfall station in our study to the Gumbel, Normal and Log-Normal laws (Kim et al., 2020), which are well adapted to the Mediterranean hydrological climate. The maximum daily rainfall series is adjusted by Hyfran plus software, using the (maximum likelihood) method.

The results obtained show that the best-fitting law is Gumbel's law, which gives good frequency values (Figure. 9). This result has been validated by the National Hydraulic Resources Agency (ANRH) of Constantine for the selected Hamma Bouziane station, then we obtained the peak flows by Gumbel adjustment using the maximum likelihood method (table 6).

**Calculation of Intensity - duration - frequency curve**

The IDF curve is a relationship between rainfall, return period, and duration: for each selected return period, rainfall is plotted against duration. It has the practical advantage of lending itself well to interpolation for different durations. To produce IDF curves, we transform maximum daily rainfall into short-duration rainfall expressed in (mm), using K. Body's formula (ANRH, 1984). The figure 10 gives us the different intensity values for different return periods.

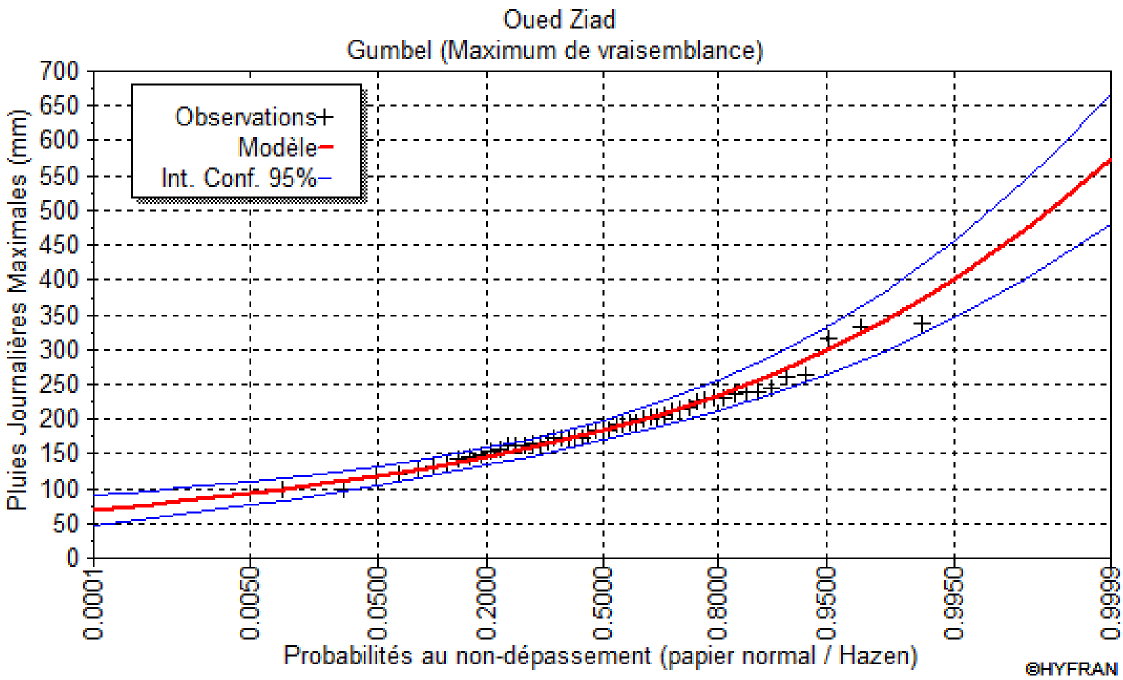


**Figure 9. Adjustment to the Gumbel low (Source; HYFRAN software, june 2023)**

**Table 6: Statistical results of peak flows by Gumbel adjustment using the maximum likelihood method, between (1968 and 2021)**

| Return Period (T) | Probability of not being exceeded | flow for different return periods | Standard deviation | Confidence interval (95%) |
|---|---|---|---|---|
| 1000 | 0.999 | 472 | 36.3 | 401- 543 |
| 100 | 0.99 | 370 | 25.3 | 320-419 |
| 50 | 0.98 | 339 | 22.0 | 296-382 |
| 20 | 0.95 | 298 | 17.6 | 263-333 |
| 10 | 0.9 | 266 | 14.4 | 238-294 |
| 5 | 0.8 | 233 | 11.2 | 211-255 |
| 2 | 0.5 | 183 | 7.24 | 169-197 |

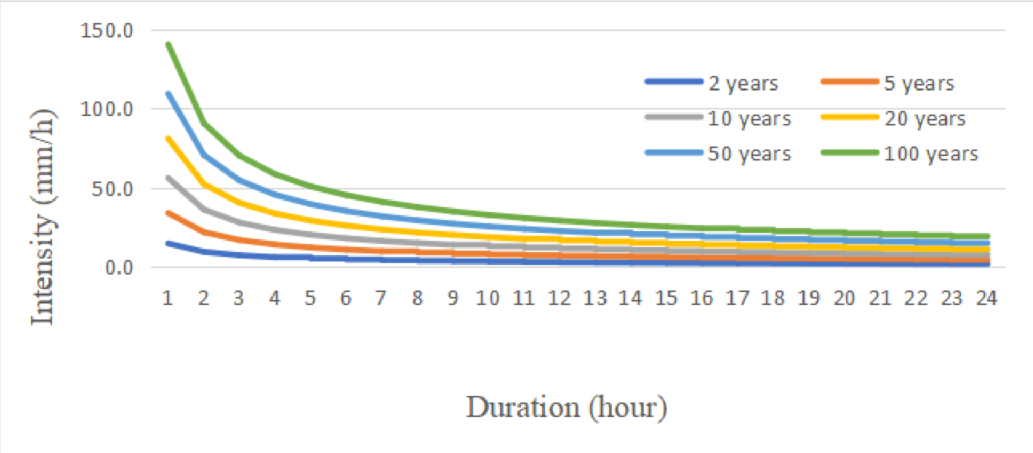


**Figure 10. Intensity-Duration-Frequency (IDF) curve for Hamma Bouziane station**

**Determination of short-duration rainfall**

The event of 19-09-2018 was recorded at the Hamma station, according to ANRH sources. An important value of 33.5 mm during 40 minutes, that is to say, an intensity of 139.6 l/s/h, made an exceptional flood, which caused important human and material damages. Using the following relationship, we transform maximum daily rainfall into short-duration rainfall of the same frequency: $Ptc = DR\ \max(tc\ /\ 24)^{b}$

Where:

Ptc: short-term rainfall of given frequency, (mm).

DR max: maximum daily rainfall of the same frequency, (mm).

Tc: time of concentration, (hours).

b: climatic exponent = 0.34.

Short-term rainfall values are shown in the following table: 07 The results obtained in the table above show that the flooding event that occurred on September 19, 2018, has a return period of 100 years.

**Determining maximum point flows**

Flow rates can be calculated using several empirical formulas. The empirical formulas used for this study are often applied to basins in northern Algeria (Zegait et al., 2022), and these formulas are also well adapted to the conditions of our watershed: (the Turraza formula, the Rational formula, the Giandotti formula, and the Mallet Gautier formula) (Table. 8).

**Flood hydrograph**

Flood hydrographs are determined using the SOKOLOVSKY method. From the graph, we can determine the three times: time of flood rise, time of flood fall, and the base time as well as the peak flow for each return period. The rising flow reaches an estimated value of 50.98 ($m^3/s$) for a return period of 100 years, this rise has a time of 1.59 h.

**Hydraulic modeling of Hec Ras flooding hazard**

To achieve the objectives of the study, we first built an HEC-RAS model of the entire Oued Ziad, made up of 39 cross-sections distributed over the entire length of the main watercourse (7 kilometers) (Figure 11). The profiles chosen are perpendicular to the direction of water flow, do not cross each other, cross the entire alluvial plain and take account of geomorphological changes in the major bed. Manning's coefficient or bed roughness coefficient provides the closest possible model to reality, taking into account water velocity on the Wadi bed and banks. On each cross-sectional profile, Manning's coefficient is set at 0.028 for the Oued Ziad banks and 0.035 for the main watercourse.

The cross-sections (in figure 12) shows the water level reached as a function of distance, and the flow velocity varies with the slope of the wadi, the values of these velocities show that the flow has a torrential regime,

The different cross-sections tell us about a series of elements:

1/ The asymmetry of the banks

2/ The narrowing and deepening of the bed of the Oued in certain sectors.

These particularities would be intimately linked to the active geological context of this region.

The elevation of the water line exceeds the minimum elevation of the Wadi Canal. Consequently, the wadi overflows on both banks.

**Table 7: Short-duration rainfall of different frequencies**

| | | | | | |
|---|---|---|---|---|---|
| Frequency | 0.999 | 0.99 | 0.98 | 0.95 | 0.90 |
| Return period (years) | 1000 | 100 | 50 | 20 | 10 |
| Ptc (mm) | 44.44 | 34.73 | 31.84 | 27.97 | 24.99 |

**Table 8: Peak flow in m3/s for different return periods**

| Frequency | 0.90 | 0.95 | 0.98 | 0.99 | 0.999 | Equations |
|---|---|---|---|---|---|---|
| Return period (year) | 10 years | 20 years | 50 years | 100 years | 1000 years | |
| Turraza | 28.82 | 35.19 | 43.39 | 50.98 | 74.55 | $Qmax = \frac{Rc \times Ptc \times A}{Tc \times 3.6}$<br>Rc: Runoff Coefficient<br>Pct.s hort-term rainfall for t=Tc, (mm)<br>A: Area in ($Km^2$)<br>Tc: Time of concentration (H) |
| Rational Formula | 23.77 | 31.04 | 40.37 | 49.55 | 70.45 | $Qmax = C \times i \times A$<br>C: runoff coefficient.<br>i: rain intensity in (mm/h) of a given frequency.<br>A: area of the watershed in ($Km^2$). |
| Giandotti | 34.51 | 38.63 | 43.97 | 47.96 | 61.37 | $Qmax = \lambda \times A \times Ptc \times \sqrt{\frac{(Hmedium - Hmin)}{4\sqrt{A}} + 1.5 \times L}$<br>A: area of the watershed in ($Km^2$).<br>L: length of the main thalweg in (m).<br>Ptc: short duration rainfall for a given frequency (m)<br>$H_{medium}$: mean elevation of the watershed.<br>$H_{min}$: minimum elevation of the watershed.<br>$\lambda$: coefficient depending on the climatic and physical parameters of the watershed ($\lambda$= 0.16) |
| Mallet-Gautier | 37.76 | 43.17 | 49.42 | 53.67 | 65.84 | $Qmax = 2K \times Log(1 + 20H)\frac{A}{\sqrt{L}}\sqrt{1 + 4LogT - LogA}$<br>K: constant depends on the characteristics of the basin between 1 and 3.<br>H: average interannual precipitation in (m).<br>A: area of the watershed in ($Km^2$).<br>L: length of the main thalweg in (Km).<br>T: return period (years) |
| Average formulas | 31.21 | 37.01 | 44.29 | 50.54 | 68.05 | / |
| Maximum flow (Qmax) | 28.82 | 35.19 | 43.39 | 50.98 | 74.55 | / |

The results that are closest to the average of the calculated methods will be used as frequency flood flows in our study: Q1000yr = 74.55 m3/s; Q100yr = 50.98 m3/s; Q50yr = 43.39 m3/s; Q20yr = 35.19 m3/s; Q10yr = 28.82 m3/s

The results of the hydrological modelling of Oued Ziad during the centennial flood show the overflow of the Oued Ziad on the national road N ° 27, affecting part of the agglomeration located downstream (Fig. 13 B). These overflows, combined with high velocities ranging from 0.03 m/s to 3.76 m/s, threatened homes, and flooded areas, particularly downstream, are significant (Fig. 13 A); hence, the hydraulic section is insufficient to evacuate these flows during flood periods. The height of water varies between 0 and 15m.

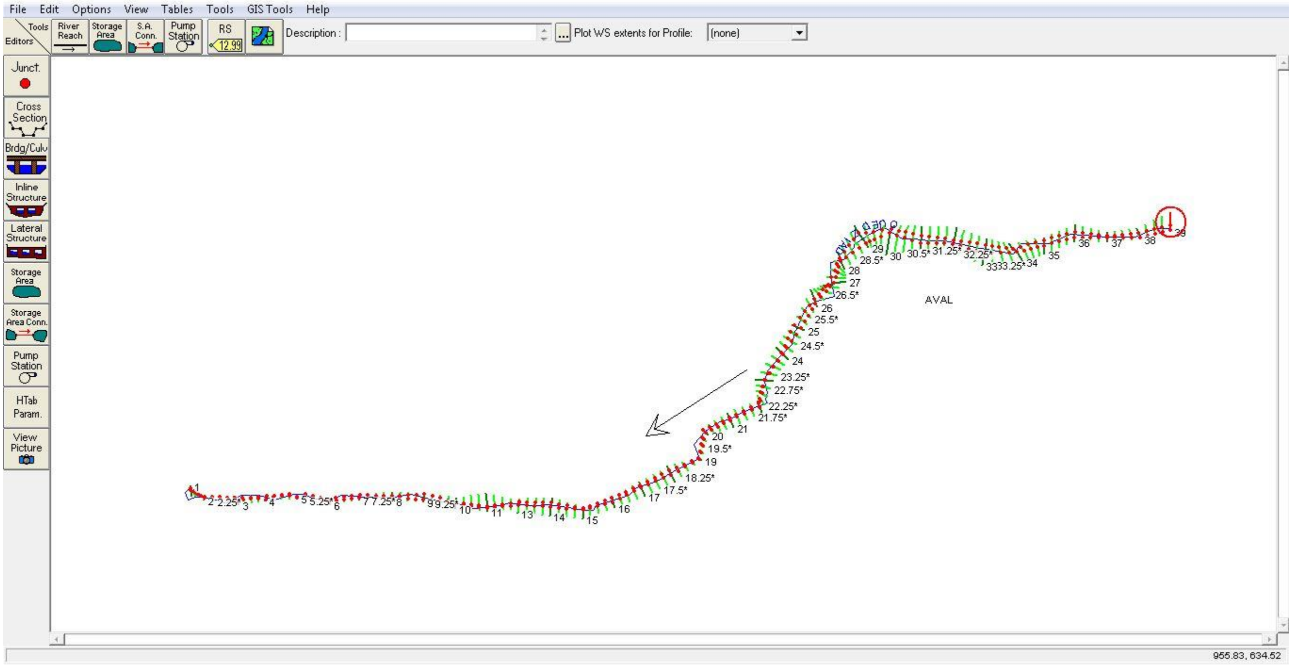


**Figure 11. Cross-sections on the Oued Ziad Watercourse**

*Source; Hec-Ras software, june 2023*

## Discussion

Morphometric analysis is used to characterize the hydrological behaviour of the watershed. The surface area of the watershed is the most important parameter because it controls the intensity of several hydrological phenomena such as flow, precipitation volume, and infiltration. For this watershed, the surface area is equal to 12.02 km2, and the perimeter is equal to 19.46 km.

The compactness index and the equivalent rectangle show that the Oued Ziad watershed has an elongated shape (Kc = 1.53, L = 7.64 km, l = 2.53 km), which means that it is more drained. The overall slope index is 53.76 m /km and the drainage density is equal to 2.43 Km / Km2, reflecting the dynamics of the watershed, the stability of the hydrographic network, and the type of surface runoff (Table.4).

The time of concentration determines the speed at which the water reaches the watershed outlet, so this variable influences the maximum flow. The result shows that the time of concentration in this catchment is very short (Tc = 1.59 h) (Table 5).

The HEC-RAS simulation is used to calculate the water level based on a specified flow rate (simulation of the 100-year flow rate). For a flow rate of 50.98 m³/s, we can observe (Table 9):

- A rise in water level to an altitude exceeding that of the sills, and consequent overflow along the channel.

- Flow velocity values vary from upstream to downstream, until cross-section number 28, where they increase to reach a maximum value of 3.76 m/s. (Table 9)

The results obtained from this simulation are close to the extent of the surface overflowed by water during the flood that occurred in September 2018 in the same study area, which confirms that this extreme hydroclimatic event has a return period of 100 years. This simulation shows that the capacity of the existing hydraulic structures is insufficient to handle the 100-year flood.

**Assessment of factors aggravating the risk of flooding from the Oued Ziad overflow channel**

Based on field investigations, we have observed that several factors are responsible for triggering the risk of flooding in the downstream part of the watershed, thus affecting the Djebli Ahmed agglomeration even during low rainfall, thus causing low peak flows. Based on this field investigation, we have identified the following conclusions:

- Anarchic urbanization and the positioning of buildings and commercial activities close to the minor bed of Oued Ziad in its downstream part of Djebli Ahmed agglomeration without taking into consideration the distance necessary for the easement (Oued), make the soil impermeable and cause an increase in the volumes of water runoff, consequently increasing the vulnerability of people and their property to the risk of flooding, which even risks collapsing their very vulnerable dwellings (Fig. 14. A).
- Lack of flood protection facilities (undeveloped/uncalibrated wadis).
- the steepness of the watershed accelerates runoff and water concentration, which can exacerbate flooding.

- Lack of cleaning, maintenance, and effective management of the problem of waste deposited in the minor bed, due to ignorance and lack of awareness on the part of the population (Fig. 14 B).
- The high flow rate and velocity of the water transport the waste and soil particles removed by the erosion process, depositing them downstream and clogging the wadi's drainage channels. The lack of maintenance of the wadi is worsening the situation, and the size of the culvert of the Wadi is insufficient to transport these dumps.

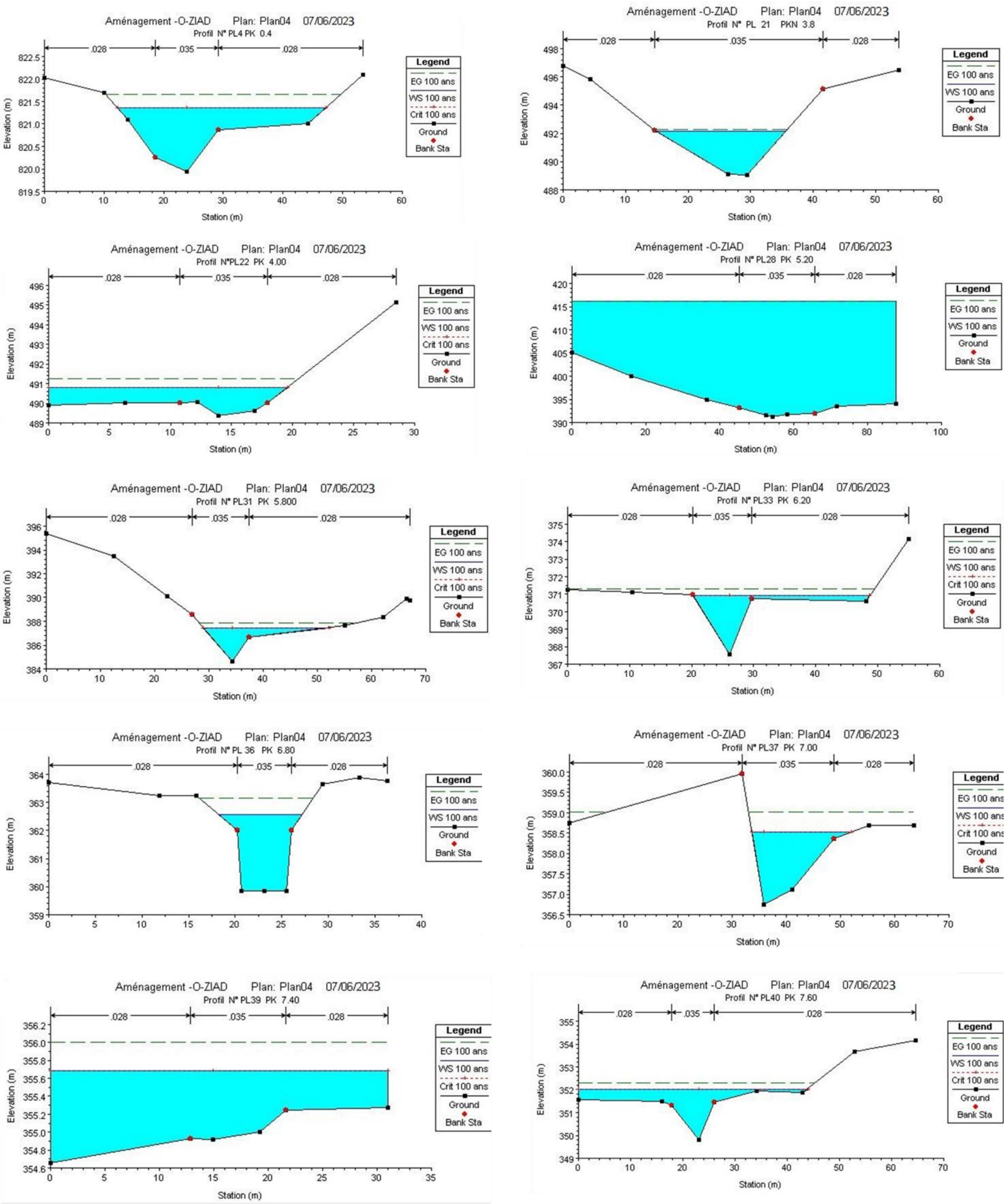


**Figure 12. Cross-sections and water levels during the 100-year flood.**

*Source: Hec-Ras software, June 2023*

**Table 9: Simulation results on Hec Ras**

| Reach | River Station | Q Total ($m^3$/s) | Min Ch El (m) | W.S. Elev (m) | Crit W.S. (m) | E.G. Elev (m) | E.G. Slope (m/m) | Velocity Chnl (m/s) | Flow Area ($m^2$) | Top Width (m) | Water level (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AVAL | 39 | 50.98 | 886.92 | 888.14 | 888.14 | 888.65 | 0.011952 | 3.2 | 16.18 | 16 | 1.22 |
| AVAL | 38 | 50.98 | 832.24 | 834.53 | 834.53 | 835.11 | 0.012476 | 3.36 | 15.18 | 13.26 | 2.29 |
| AVAL | 37 | 50.98 | 819.93 | 821.36 | 821.36 | 821.66 | 0.008033 | 2.74 | 22.09 | 34.99 | 1.43 |
| AVAL | 36 | 50.98 | 775.23 | 777.63 | 777.63 | 778.24 | 0.012609 | 3.46 | 14.75 | 12.28 | 2.4 |
| AVAL | 35 | 50.98 | 762.55 | 765.08 | 765.08 | 765.72 | 0.012809 | 3.55 | 14.38 | 11.38 | 2.53 |
| AVAL | 34 | 50.98 | 711.71 | 712.76 | 712.76 | 713.17 | 0.013238 | 2.84 | 17.95 | 22.07 | 1.05 |
| AVAL | 33 | 50.98 | 675.95 | 676.71 | 676.71 | 677.02 | 0.014647 | 2.45 | 20.83 | 34.84 | 0.76 |
| AVAL | 32 | 50.98 | 652.75 | 654.07 | 654.07 | 654.53 | 0.012896 | 3 | 16.99 | 18.78 | 1.32 |
| AVAL | 31 | 50.98 | 610.38 | 612.22 | 612.22 | 612.68 | 0.012719 | 3 | 16.97 | 18.48 | 1.84 |
| AVAL | 30 | 50.98 | 606.23 | 607.43 | 607.43 | 607.88 | 0.012902 | 2.97 | 17.15 | 19.07 | 1.2 |
| AVAL | 29 | 50.98 | 593.62 | 594.3 | 594.3 | 594.55 | 0.015579 | 2.2 | 23.19 | 47.87 | 0.68 |
| AVAL | 28 | 50.98 | 576.78 | 579.64 | 579.64 | 580.36 | 0.013474 | 3.76 | 13.55 | 9.49 | 2.86 |
| AVAL | 27 | 50.98 | 561.25 | 562.75 | 562.75 | 563.29 | 0.012478 | 3.26 | 15.64 | 14.47 | 1.5 |
| AVAL | 26 | 50.98 | 555.02 | 557.13 | 557.13 | 557.68 | 0.012576 | 3.26 | 15.62 | 14.56 | 2.11 |
| AVAL | 25 | 50.98 | 548.29 | 550.03 | 550.03 | 550.4 | 0.013854 | 2.7 | 18.9 | 25.44 | 1.74 |
| AVAL | 24 | 50.98 | 541.81 | 543.97 | 543.97 | 544.65 | 0.012505 | 3.68 | 14.11 | 10.68 | 2.16 |
| AVAL | 23 | 50.98 | 537.38 | 538.88 | 538.88 | 539.22 | 0.009446 | 1.61 | 20.02 | 29.8 | 1.5 |
| AVAL | 22 | 50.98 | 516.97 | 519.1 | 519.1 | 519.64 | 0.012405 | 3.23 | 15.77 | 14.78 | 2.13 |
| AVAL | 21 | 50.98 | 507.21 | 509.52 | 509.52 | 510.17 | 0.012444 | 3.6 | 14.18 | 10.79 | 2.31 |
| AVAL | 20 | 50.98 | 489.03 | 492.16 | | 492.26 | 0.00122 | 1.4 | 36.4 | 20.76 | 3.13 |
| AVAL | 19 | 50.98 | 489.38 | 490.8 | 490.8 | 491.25 | 0.010267 | 3.01 | 17.24 | 19.55 | 1.42 |
| AVAL | 18 | 50.98 | 474.88 | 476.93 | 476.93 | 477.53 | 0.012236 | 3.41 | 14.93 | 12.53 | 2.05 |
| AVAL | 17 | 50.98 | 463.84 | 465.87 | 465.87 | 466.5 | 0.012535 | 3.52 | 14.49 | 11.67 | 2.03 |
| AVAL | 16 | 50.98 | 447.09 | 449.35 | 449.35 | 449.82 | 0.01352 | 3.03 | 16.83 | 18.41 | 2.26 |
| AVAL | 15 | 50.98 | 441.73 | 444.11 | 444.11 | 444.84 | 0.012474 | 3.8 | 13.46 | 9.39 | 2.38 |
| AVAL | 14 | 50.98 | 425.34 | 427.3 | 427.3 | 427.89 | 0.012518 | 3.4 | 15 | 12.97 | 1.96 |
| AVAL | 13 | 50.98 | 401 | 416.06 | | 416.06 | 0 | 0.03 | 1781.57 | 87.79 | 15 |
| AVAL | 12 | 50.98 | 413.66 | 415.45 | 415.45 | 416 | 0.01284 | 3.29 | 15.51 | 14.39 | 1.79 |
| AVAL | 11 | 50.98 | 407.77 | 409.67 | 409.67 | 410.23 | 0.009389 | 3.39 | 15.9 | 14.75 | 1.9 |
| AVAL | 10 | 50.98 | 384.65 | 387.46 | 387.46 | 387.88 | 0.007782 | 3.08 | 19.17 | 23.17 | 2.81 |
| AVAL | 9 | 50.98 | 374.75 | 376.31 | 376.31 | 376.77 | 0.0129 | 2.99 | 17.05 | 18.75 | 1.56 |
| AVAL | 8 | 50.98 | 367.55 | 370.93 | 370.93 | 371.3 | 0.006173 | 2.82 | 20.98 | 28.46 | 3.38 |
| AVAL | 7 | 50.98 | 363.92 | 365.97 | 365.97 | 366.56 | 0.011085 | 3.44 | 15.11 | 12.84 | 2.05 |
| AVAL | 6 | 50.98 | 360.89 | 363.75 | | 363.99 | 0.003029 | 2.2 | 23.18 | 12.15 | 2.86 |
| AVAL | 5 | 50.98 | 359.85 | 362.57 | | 363.14 | 0.00761 | 3.4 | 15.56 | 8.93 | 2.72 |
| AVAL | 4 | 50.98 | 359.28 | 361.2 | 361.2 | 361.9 | 0.012728 | 3.68 | 13.84 | 10.05 | 1.92 |
| AVAL | 3 | 50.98 | 356.75 | 358.53 | 358.53 | 359.02 | 0.011309 | 3.11 | 16.62 | 18.38 | 1.78 |
| AVAL | 2 | 50.98 | 354.92 | 355.68 | 355.68 | 356.01 | 0.008066 | 1.99 | 21.36 | 30.97 | 0.76 |
| AVAL | 1 | 50.98 | 349.79 | 352.03 | 352.03 | 352.3 | 0.005691 | 2.62 | 25.09 | 43.94 | 2.24 |

These results confirm the need for additional preventive measures to protect people and property from the risk of flooding. Hence the need to install additional gutters to allow water to flow away during extreme floods, to raise public awareness of the risk of flooding, and to clean and maintain the Oued and its banks on an ongoing basis.


**Figure 13. A/Flood hazard modelling map during the centennial return period of Oued Ziad; B/ the overflow of Oued Ziad on national road 27**


**Figure 14. Status of Oued Ziad and causal factors; A) Anarchic urbanization occupying the right bank of the Wadi; B) waste deposited in the minor bed of the Wadi**

## Conclusions

This study enables us to determine the overflow areas in the Oued Ziad watershed. Hydraulic modelling using HEC-RAS software allows us to simulate the 100-year flood and determine that protection against floods requires forecasting and prevention measures, which integrate the various factors likely to influence the risk of flooding. It is not only a question of mapping flood-prone areas, but also regulating land use, maintaining waterways and minimizing anthropogenic factors, and managing watersheds (Lahsaini & Tabyaoui, 2018).

This work has shown that flooding has also become a critical risk in Constantine. They must be taken seriously into account in development programs.

The use of geographic information systems (Arcmap) in conjunction with Hec Ras hydrological modelling software provides a powerful spatial decision support system that enables flood risk to be mapped effectively, providing a clear understanding of the extent and height of the water, as well as identifying the factors aggravating its dynamics for better management and maintenance of water resources, which are a non-renewable natural resource.

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## Author contribution

Conceptualization, M.Y, and A.B; T.E. K, methodology, M.Y, A. B; formal analysis, M.Y; investigation, C.B, M.Y, F, G; writing – original draft preparation, M. Y, writing – review and editing, F. G, C. B, and M. Y.

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## Conflicts of interest

The authors declare no conflict of interest.

## References

Abdelshafy, M., & Mostafa, A. (2021). Flash Flood Modeling Using HEC-RAS (2D) model on Wadi Reem in the western region, Kingdom of Saudi Arabia. J. Egypt. Acad. Soc. Environ. Develop, 22(1), 17–32. www.jades.journals.ekb.eg

AL-Hussein, A. A. M., 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 (Switzerland), 14(22). https://doi.org/10.3390/w14223779

Awad, T., Bansode, M., Chavan, R., & Bhise, R. (2022). FLOOD MANAGEMENT BY USING HEC-RAS SOFTWARE. In International Research Journal of Modernization in Engineering Technology and Science. Vol 04, Issue 06. www.irjmets.com.

Bekhira, A., Habi, M., & Morsli, B. (2019). Management of hazard of flooding in arid region urban agglomeration using HEC-RAS and GIS software: The case of the Bechar’s city. Journal of Water and Land Development, 42(1), 21–32. https://doi.org/10.2478/jwld-2019-0041

Benabbas, C. (2006). Mio-Plio-Quaternary evolution of the continental basins of north-eastern Algeria: contribution of photogeology and morpho-structural analysis). Ph.D thesis. University of Mentouri, Constantine, Algeria. 256 p. (in French)

Benabbas. C., Bouedja, F., & Benzid, Y. (2011). Néotectonique, déformation du relief et risque sismique dans la région de Constantine. IV éme Colloque International « directions contemporaines dans l’étude du territoire- Gestions du territoire, des aléas et de la ville » ; Bucarest, 22-27 Juin.

Bilașco, Ș., Hognogi, G. G., Roșca, S., Pop, A. M., Iuliu, V., Fodorean, I., ... & Sestras, P. (2022). Flash flood risk assessment and mitigation in digital-era governance using unmanned aerial vehicle and GIS spatial analyses case study: small river basins. Remote Sensing, 14(10), 2481

Brunner, G. W. (2016). HEC-RAS river analysis system user’s manual version 5.0. US Army Corps of Engineers, 962. http://www. hec.usace.army.mil/software/hec-ras/downloads.aspx

Buta, C., Mihai, G., & Stănescu, M. (2017). Flash floods simulation in a small drainage basin using HEC-RAS hydraulic model. Ovidius University Annals of Constanta - Series Civil Engineering, 19(1), 101–118. https://doi.org/10.1515/ouacsce-2017-0009.

Costache, R., Popa, M. C., Bui, D. T., Diaconu, D. C., Ciubotaru, N., Minea, G., & Pham, Q. B. (2020). Spatial predicting of flood potential areas using novel hybridizations of fuzzy decisionmaking, bivariate statistics, and machine learning. Journal of Hydrology, 585, 124808.

Derdour, A., Bouanani, A., & Babahamed, K. (2017). Hydrological modeling in semi-arid region using HEC-HMS model. case study in Ain Sefra watershed, Ksour Mountains (SW-Algeria). Journal of Fundamental and Applied Sciences, 9(2), 1027. https://doi.org/10.4314/jfas.v9i2.27

Gao, P., Gao, W., & Ke, N. (2021). Assessing the impact of flood inundation dynamics on an urban environment. Natural Hazards, 109(1), 1047–1072. https://doi.org/10.1007/s11069-021-04868-6

Grecu, F. (2016). Hazarde si riscuri naturale, Editura Universitara, Bucuresti, ISBN 978-606-28-0392-6, https://doi 10.5682/9786062803926, 354 p

Grecu, F., Zaharia, L., Ioana-Toroimac, G., Armas, I. (2017), Floods and flash-floods related to river channel dynamics in vol. Radoane M., Vespremeanu Stroe F. eds, Landform dynamics and evolution in Romania, Springer Verlag, p. 821 – 844, ISBN 978-3-319-32589-7 DOI 10.1007/978-3-319-32589-7_33

Grecu, F. (2018 a). Geomorphologic Hazard in Romania.Typology and Areal distribution In Water Management and the Environnment. Case Studies ed. Martina Zelenakova, Springer International Publ, https://doi.org 10.1007/978-3-319-79014 -5_5, p.85 - 99.

Grecu, F. (2018 b). Geomorfologie dinamică pluvio-fluvială. Teorie şi aplicaţii, Editura Universitară, 480 p., 264 figuri, 70 tabele, 503 titluri bibliografice, index de termini, simboluri

Grecu, F., Benabbas, C., Teodor, M., Yakhlefoune, M., Săndulache, I., Manchar, N., Vișan, G. (2021). Risk of Dynamics of the River Stream in Tectonic Areas. Case studies: Curvature Carpathian - Romania and Maghrebian Chain - Algeria. Forum geographic. XX(1), 5-22. doi:10.5775/fg.2021.021.i

Jalilzadeh, A., & Behzadi, S. (2020). Flood Mapping and Estimation of Flood Water-Level Using Fuzzy Method and Remote Sensing Imagery (Case Study: Golestan Province, Iran). Vol XIX, Issue 2, pp. 165-174 http://dx.doi.org/10.5775/fg.2020.062.d

Kashfy, M., Aminuddin, A., Nor, Z., Ngai, CW. (2020). HEC-RAS One-Dimensional Hydrodynamic Modelling for Recent Major Flood Events in Pahang River. In: Mohamed Nazri, F. (eds) Proceedings of AICCE'19. AICCE 2019. Lecture Notes in Civil Engineering, vol 53. Springer, Cham. https://doi.org/10.1007/978-3-030-32816-0_83

Kim, V., Tantanee, S., & Suparta, W. (2020). Gis-based flood hazard mapping using hec-ras model: A case study of lower mekong river, cambodia. Geographia Technica, 15(1), 16–26. https://doi.org/10.21163/GT_2020.151.02

Lahsaini, M., & Tabyaoui, H. (2018). Modelisation Hydraulique Mono Dimensionnel Par HEC RAS, Application Sur L'oued Aggay (Ville De Sefrou). European Scientific Journal, ESJ, 14(18), 110. https://doi.org/10.19044/esj.2018.v14n18p110

LASRI, M. (2019). Flood hazard mapping in the town of Fez: From hydrological modeling to hydraulic simulation. Environmental and Water Sciences, public Health and Territorial Intelligence Journal, 3(2), 113-123. https://doi.org/10.48421/IMIST.PRSM/ewash-ti-v3i2.16083

Mătreaţă, M., Mătreaţă, S., Costache, R.-D., Mihalcea, A., & Manolache, A. V. (2016). Assessment of Flash Flood Hazard Maps Using Different Threshold Values and Indices Methods. Forum Geografic, XV(Suppl. 2), 49–54. https://doi.org/10.5775/fg.2016.059.s.

Nkwunonwo, U. C., Whitworth, M., & Baily, B. (2020). A review of the current status of flood modelling for urban flood risk management in the developing countries. Scientific African, 7, e00269.

Sunilkumar, P., & Vargheese, K. O. (2017). Flood modelling of mangalam river using GIS and HEC-RAS. Department of Civil Engineering, Government Engineering College, Thrissur, India.

Ongdas, N., Akiyanova, F., Karakulov, Y., Muratbayeva, A., & Zinabdin, N. (2020). Application of hec-ras (2d) for flood hazard maps generation for yesil (ishim) river in kazakhstan. Water (Switzerland), 12(10), 1–20. https://doi.org/10.3390/w12102672

Prăvălie, R., & Costache1, R. (2014). The analysis of the susceptibility of the flash-floods' genesis in the area of the hydrographical basin of Bâsca Chiojdului river. Forum geografic. Studii și cercetări de geografie și protecția mediului XIII(1), 39–49. https://doi.org/10.5775/fg.2067-4635.2014.089.i

Rai, P. K., & Mohan, K. (2014). Remote Sensing data & GIS for flood risk zonation mapping in Varanasi District, India. Forum Geografic, XIII(1), 25–33. https://doi.org/10.5775/fg.2067-4635.2014.041.i

Tegenie, E. B., & Berhe, F. T. (2021). Floodplain Inundation Modeling and Mapping for Geray River: Nile Basin, Ethiopia. Vol (3). Issue (6). https://doi.org/10.3759/jowrem.v6i3.3057

Thapa, S., Shrestha, A., Lamichhane, S., Adhikari, R., & Gautam, D. (2020). Catchment-scale flood hazard mapping and flood vulnerability analysis of residential buildings: The case of Khando River in eastern Nepal. Journal of Hydrology: Regional Studies, 30. https://doi.org/10.1016/j.ejrh.2020.100704

Uca, Lamada, M., Nyompa, S., & Haris, N. A. (2022). Morphometry and Topographic Wetness Index Analysis for flood inundation mapping in Mata Allo watershed (South Sulawesi, Indonesia). Forum Geografic, 21(2), 133–145. https://doi.org/10.5775/fg.2022.105.d

Xafoulis, N., Farsirotou, E., Kotsopoulos, S., & Alamanis, N. (2022). Flood hazard assessment in a mountainous river basin in Thessaly, Greece, based on 1D/2D numerical simulation. Energy Nexus, 8, 100142. https://doi.org/10.1016/j.nexus.2022.100142

Yalcin, E. (2020). Assessing the impact of topography and land cover data resolutions on twodimensional HEC-RAS hydrodynamic model simulations for urban flood hazard analysis. Natural Hazards, 101(3), 995-1017.

Yerramilli, S. (2012). A Hybrid Approach of Integrating HEC-RAS and GIS Towards the Identification and Assessment of Flood Risk Vulnerability in the City of Jackson, MS. American Journal of Geographic Information System, 1(1), 7–16. https://doi.org/10.5923/j.ajgis.20120101.02

Zegait, R., Şen, Z., Pulido-Bosch, A., Madi, H., & Hamadeha, B. (2022). Flash Flood Risk and Climate Analysis in the Extreme South of Algeria (the Case of In-Guezzam City). Geomatics and Environmental Engineering, 16(4), 157–185. https://doi.org/10.7494/geom.2022.16.4.157

Zellou B, Rahali H (2016) Assessment of reduced-complexity landscape evolution model suitability to adequately simulate flood events in complex flow conditions. Nat Hazards 86 (1):1–29