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Published by the Faculty of Engineering, Khon Kaen University, Thailand

Analysis and forecasting flood risk mapping of the Medjerda River at Boussalem town, in Tunisia

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Received 23 January 2023
Revised 17 August 2023
Accepted 23 August 2023

Abstract

This work aims to make a comprehensive analysis of the floods on the crossing part of Boussalem city (North Tunisia) in the framework of possible future scenarios for different return periods. A 2D hydrodynamic model based on TELEMAC-2D for flood simulation is developed taking into account the dynamics of the flows and the floodplains, after processing and analysing the available topographic and hydrological data. A lidar survey and an Ortophoto covering the project area (wadi beds and floodplain) were processed to define the different land use components. They are then converted to produce a bathymetric mesh. Five flood hydrographs corresponding to return periods of 5, 10, 20, 50 and 100 years were constructed based on an analysis of historical floods recorded in Boussalem. After calibration and validation of the model, the main conclusions of the study revealed five representative maps made from the results of the water level heights generated by Telemac2d for the events with different return periods. The final synthetic map presents the development of the spatial distribution of the flood risk over the urban area, it shows that the flooded areas in the city represent respectively 30%, 50% and 86% for the 20, 50 and 100 years return period events, which shows a strong risk for these events.

Keywords: Flooding, Bidimensional model, Hydraulic simulation, Medjerda River, TELEMAC-2D, Flood risk mapping

1. Introduction

Floods are one of the world's most significant natural hazards, affecting millions of people every year. With climate change and human practices, the problem of flooding is worsening, causing not only loss of life, but also material damage and high economic costs for entire communities. This is the case of the town of Boussalem, located in the northwest of Tunisia, which is crossed by the Medjerda, the longest and only Perennial River in the country, the nature of the semi-arid climate of this city causes intense rainfall for short periods of time, and also induces sudden runoff. These factors make the city at high risk of flooding difficult to predict. The Medjerda is an international river, with a catchment area of 23,500 km^2 [1], and its source is located in Algeria near Souk Ahras in the Constantinois. Almost one third of its catchment area is in Algeria and it has a total length of 460 km, with an annual input of almost half of Tunisia's water resources. Because of its importance, the Medjerda has been the subject of numerous studies to understand its hydrological and hydraulic characteristics.

The water resources of the Medjerda, average 1 billion m^3/year, representing 37% of the Tunisia surface water, and 22% of the renewable water resources of the country. The watershed regularly experiences torrential rains during the season from September to March, causing bank degradation and bottom erosion [2]. In particular, in recent years, frequent downpours occurred in 2000, 2003, 2004, 2005, 2009, 2012 and 2015 and corresponding major floods caused significant damage in the downstream Medjerda basin in the north of the country.

Reliable forecasting and mapping tools are essential for flood risk prevention and assessment. Flood modelling is a method to simulate the behaviour of hydrological systems and to estimate the consequences of floods. Hydraulic models supported by GIS can perfectly transform water surface elevations into a flood map at any point [3]. Indeed, topography plays a vital role in transforming water surface elevations into flood map [4]. The flood maps developed indicate the critical areas at risk for a given rainfall event, and thus giving the opportunity to issue early warnings and plan measures to minimise damage.

The two-dimensional TELEMAC-2D model is a powerful tool for the simulation and prediction of free- surface flow problems such as those in rivers for flood modelling. Despite its complexity, it provides us with a very high-quality hydraulic expertise support in terms of results analysis, and understanding of hydraulic phenomena in the presence of complex flow areas.

For the present study, the objective is to recognize the flood risk by developing risk maps for Boussalem city. A 2D hydrodynamic model is developed for the study area using TELEMAC-2D and simulated to generate flood maps. Five different scenarios of probable extreme flood events for the return intervals of 5 years, 10 years, 20 years, 50 years and 100 years are generated. The model input/output is processed in the Blue Kenue tool to build the mesh and read the different model results for the different scenarios.

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doi: 10.14456/easr.2023.47

The model results are then processed in QGIS (Geographic Information System) to analyse the flooding and to develop flood risk maps for the different scenarios. QGIS not only visualises the flood risk of the study area in the form of a detailed flood risk map, but also performs post-processing for the generation of the mesh and the identification of land use necessary for the roughness coefficient definition.

2. Description of the model

The most commonly used models are one- and two-dimensional [5]. 1D models are mainly used to describe inflows without taking into account the extensive vertical distribution on floodplains that occurs during flooding, because they plot only the water level between the cross sections. To simulate flooding processes and to study river hydrodynamics, two-dimensional models should be used [6]. Two-dimensional (2D) numerical simulations are nowadays an important tool for modelling and mapping floods [7]. In this study, we will apply the two-dimensional model TELEMAC-2D to assess the risks related to flooding in Boussalem city. The model was developed by the National Laboratory for Water and the Environment (LNHE) of the French Electricity Company (EDF). [8]. TELEMAC-2D is used to simulate free surface flows in two dimensions of horizontal space [9], that are well adapted for studing water movements in shallow water domains: rivers, coastal areas, estuaries and lakes.

To solve the water flow equations in bi-dimensional horizontal space, TELEMAC-2D uses a finite element structure on an unstructured triangular mesh [10]. These equations describe the water mass conservation, and the momentum one in the two space horizontal directions, in each node. The main simulation results are the water height, and the average velocity over depth for each mesh node [11]. We have to note that friction coefficient, turbulence, wetting section and Coriolis coefficient as well as various physical phenomena were considered by the model.

TELEMAC-2D equations:

Continuity equation $$\mathrm{u}\ \mathrm{div}(\vec{\mathrm{u}}) + \frac{\partial \mathrm{h}}{\partial \mathrm{t}} + \vec{\mathrm{u}}\ \vec{\nabla}(\mathrm{u}) = \mathrm{S_h} \quad (1)$$

Momentum along x $$\vec{\mathrm{u}}\ \vec{\nabla}(\mathrm{u}) + \frac{\partial \mathrm{u}}{\partial \mathrm{t}} = \mathrm{S_x} + \frac{1}{\mathrm{h}}\mathrm{div}\left(\mathrm{h}\nu_\mathrm{t}\vec{\nabla}\mathrm{u}\right) - \mathrm{g}\frac{\partial \mathrm{z}}{\partial \mathrm{x}} \quad (2)$$

Momentum along y $$\vec{\mathrm{u}}\ \vec{\nabla}(\mathrm{v}) + \frac{\partial \mathrm{v}}{\partial \mathrm{t}} = \mathrm{S_y} + \frac{1}{\mathrm{h}}\mathrm{div}\left(\mathrm{h}\nu_\mathrm{t}\vec{\nabla}\mathrm{v}\right) - \mathrm{g}\frac{\partial \mathrm{z}}{\partial \mathrm{y}} \quad (3)$$

g : acceleration of gravity (m/s²)
h : depth of water (m)
u, v : components of velocity (m/s),
ν_t : momentum diffusion coefficients (m²/s),
z : free surface elevation (m),
t : time (s),
x, y : horizontal space coordinates (m),
S_h : source or sink of fluid (m/s),
S_x, S_y : source or sink terms in dynamic equations (m/s²),

h, u and v are unknowns. Sx and Sy (m/s²) are source terms representing wind, Coriolis force, bottom friction and a source or sink of momentum within the domain.

Terms of these equations are determined in one or more steps

- Advection of u, h and v
- Diffusion, Propagation and source terms of the dynamic equation

h, u and v are advected separately, and it is then possible to solve diffusion equation using a fixed advection velocity field. turbulence and viscosity are given by using a model simulating the transport of turbulent quantities epsilon (turbulent dissipation) and k (kinetic turbulent energy).

3. Study area

For our case study, we are interested in the city of Boussalem, located on the banks of the Medjerda (watershed area is 16,230 km²), which is located between the coordinates 36° 36′ 40″ North, 8° 58′ 11″ East at the level of the alluvial plain of the upper Medjerda valley. Boussalem has a temperate Mediterranean climate with hot, dry summers according to the Köppen-Geiger classification. Over the year, the average temperature is 18.4°C and rainfall averages 454.8 mm. The city of Boussalem has more than 36,000 inhabitants distributed in 8,330 households and 8,841 dwellings, it has also a road, rail and industrial infrastructure [12]. The urban area measures about 556 hectares. Urban floods cause high damages, and so mapping risk flood has become essential for protection and evacuation planning [13]. Land use is described in three main sections: Agriculture, which remains the main economic activity, urban industrial zones (mainly agri-food) and urban residential area. The Boussalem town has been flooded frequently [14], over the last twenty years or so there have been six flooding events, in 2000, 2003, 2005, 2009, 2012 and 2015 respectively, which have caused significant damage.

The area considered to be modelled under TELEMAC 2D extends over a watercourse length of about 7.2 kilometers, a width of about 7200 meters, and a total surface area of nearly 3000 ha. The studied section describes the crossing of the city of Bousselem, it has a regular slope of 30 cm/km (0.01%) and is fed by the tributary Oued Bouhertma. From the geo-spatial analysis of the available orthophoto exploited, we can distinguish 5 different zones of ground occupation which are: minor bed, middle bed occupied by Tamarix, middle bed cleaned or exploited, urban zone and agricultural zone (Figure 1).

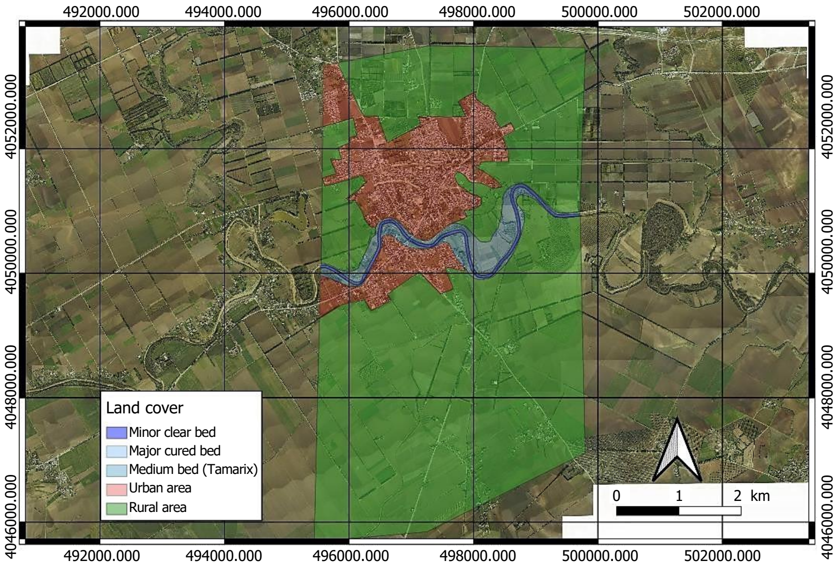

Figure 1 Location of the study area (town of Boussalem: 36° 36′ 40″ North, 8° 58′ 11″ East)

4. Methodology

To achieve the objective of the study, we choose to build a flood magnitude modelling and measurement scheme consisting of the following four processes:

- Collection of topographic and hydrological data carried out in studies within the framework of the Water Storage and Flood Protection Programme, from the General Directorate of Dams and Large Hydraulic Works (DGBGTH). The topographic data consists of Ortho-photo with pixel size=10 cm and a Lidar DEM survey. The hydrological data cover the flow and height records at the Boussalem station over a 92-years period.
- Post-processing of topographic data for land use identification and mesh reconstruction.
- Analysis of hydrological data and reconstruction of flood hydrographs for different return periods.
- Model calibration and validation of results.

4.1 Post processing of geometric data

The accurate representation of the river geometry is a crucial element for successful hydraulic modelling. In the present case, the study area is characterised by very meandering rivers with predominantly rural floodplains, embanked infrastructure and high human occupation near the rivers. In order to have a desired degree of accuracy in the definition of the different flow parameters (water height, velocity) in relation to our objectives, a lidar survey covering the considered area (wadi beds and floodplain) was collected from the Agriculture Ministry. 37 cross-sections were taken to represent the bathymetry of the wadi's minor bed. The shooting and data processing were carried out during November and December 2019. This survey allows to identify the complexity of the flow mechanisms in the minor bed and the overflows in the major bed.

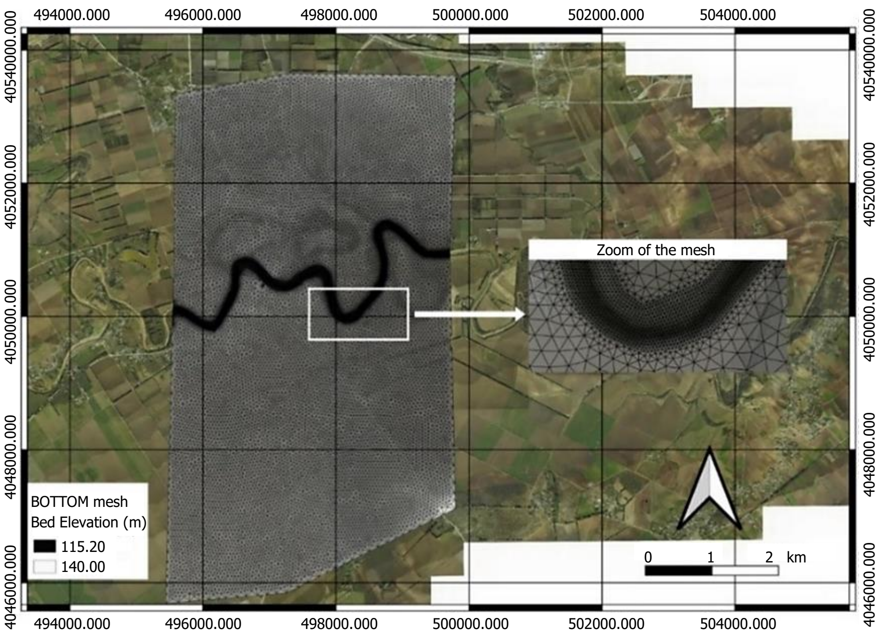

Figure 2 Grid of the study area

A raster dataset was converted into a geodatabase to merge the lidar raster files; after spatial processing in QGIS a DEM with a resolution of 1 m/pixel was created. Then we produced a set of points in shp file format, where each point has xyz coordinates. The generation of the TELEMAC-2D model, requires a spatial representation of the domain using a computer mesh, the resolution of the mesh influences the performance of the model [15], hence a triangular unstructured surface mesh was developed by the Blue Kenue model, using the finite element method after processing the imported point set in shp file format.

The relatively small study area makes it possible to reduce the total duration of the simulations and to avoid the heaviness of the calculation, and to carry out a rather precise mesh (from the available topographic data). The size of the mesh varies according to the zones of the model, the aim being to have an acceptable number of calculation nodes which allows both to correctly represent the topography and bathymetry of the natural terrain and to keep calculation times reasonable. The mesh size is about 5m longitudinally in order to correctly represent the flows along the main direction. For the major riverbed the mesh size is 50 m. This mesh size may seem rather large but it achieves the objective of the study to deliver an accurate mapping of the flood-prone areas. It is therefore not possible to represent the terrain topography in the major bed with greater precision. In fact, taking into account_these details will increase the number of mesh area and the computational time. As a result, there are a total of 24624 unstructured triangular meshes and 48947 nodes (Figure 2).

4.2 Boundary condition

TELEMAC-2D imposes several forms of boundary conditions for the modelling of the river flow, the boundary conditions file is a mandatory file. It is created using the same mesh as the previous file. Once created, it is used to delineate the inputs/outputs in the domain. Two open boundaries are represented by green or blue triangles depending on whether they are assigned to water depth (output) and flow over 50 hours base time to our reconstructed flood hydrographs for different return periods introduced at one-hour interval (input) data. The other nodes on the boundaries of the study area are represented by points that are part of the boundaries kept closed.

4.3 Reconstruction of flood hydrographs

We chose flow data for the upstream boundaries of TELEMAC-2D as input to determine the flood depths for various return periods during the calculation time. The flood flow analyses are performed to obtain the largest flood that can occur in different times. Indeed, reliable flood estimates are essential to establish the flood risk map in our study area.

We chose to associate flow data for the upstream boundaries and height data for the downstream boundaries of the wadi. We also reconstructed 5 triangular flood hydrographs corresponding to return periods of 5, 10, 20, 50 and 100 years.

The catchment area of the Medjerda at the town of Boussalem is very large (16,230 km²). For the choice of the peak flows at different return periods concerning the Boussalem station, we will focus on the estimates carried out in studies within the framework of the Program of water storage and protection against floods, at the General Directorate of Dams and Large Hydraulic Works (DGBGTH). Because these values have been calculated by statistical adjustment from recordings of various rainfall stations (45 stations) located in the sub-catchments of the Medjerda and its tributaries over a period of up to 100 years. We choose these adjustments because they treat the whole catchment area more than the empirical formulae which are based on one average rainfall of the whole catchment area.

For the choice of floods with a return period of 5, 10, 20 and 50 years, we have adopted the values calculated by ORSTOM 1981 which are the closest to the averages (Table 1). For the choice of the 100-year flood, we can consider the highest recorded flood (3,180 m³/s), that was the one of March 1973, as a reference flood. Indeed, it is the highest over a 120-year period.

For the choice of the base time we focused on the analysis we made from observation of the flood records observed in the station of Boussalem over 92 years period (Figure 3).

Table 1 Flood flows for different return periods (m³ /s) [16]

Study	Return period (years)				
	5	10	20	50	100
ORSTOM 1981	850	1250	1650	2350	2950
JICA 2009	1100	1550	2100	3000	3700
JICA 2018	-	950	1450	2400	4500

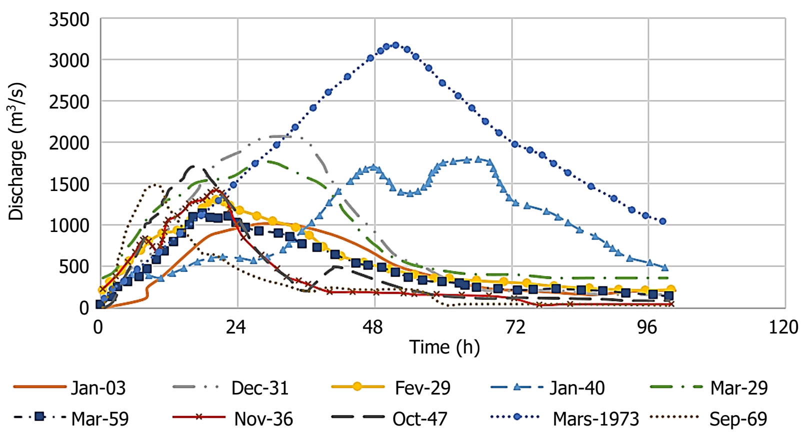

Figure 3 Flood hydrographs at the Boussalem station

The town of Boussalem is the site of convergence of the floods from the Medjerda, Bouherthma, Tessa and Mellegue wadis. This partly explains why very high successive floods have been recorded (Figure 3). Boussalem is a main hydrometric station. By superimposing the hydrographs of past floods since 1929 at this station, it can be seen that the highest peak flow exceeded 3000 m³/s in March 1973.

Table 2 Flood flows and rise time at the Boussalem station (m3/s)

Flood	1929 (Feb.)	1929 (Mar.)	1931	1936	1940	1947	1959	1969	1973	2003
Peak flow rate	1300	1760	2060	1420	1780	1700	1140	1485	3180	1000
Time to get peak (hr)	24	27	29	23	48	20	22	10	50	28

There is a difference between the pattern of hydrographs for autumn floods and winter or spring floods. Indeed, the floods of September, October and November are characterised by rapid rise and fall in time, whereas those of December, January, February and March are more spread out in time with a much slower fall [17]. With the exception of 1973, we observe that the rise time has an average of about 25 hours (Table 2). Therefore, we can choose to give a base time of 50 hours to our reconstructed flood hydrographs for the different return periods (Figure 4).

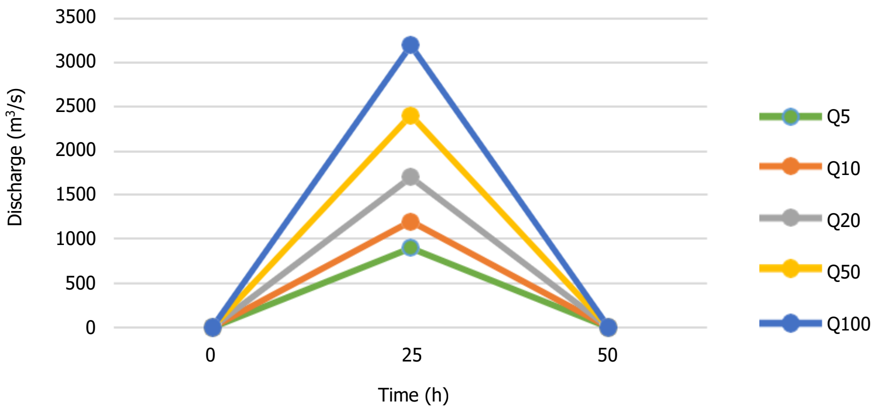

Figure 4 Flood hydrographs for different return periods

4.4 Model calibration and identification of the roughness coefficient

According that there is an excessive development of Tamaris vegetation on the wadi beds, leading to an increased occurrence of flooding, particularly in the town of Boussalem [18], cleaning works of the Medjerda wadi and some of its tributaries began in 2015 and completed in 2018. Since, a regular cleaning works are carried out annually to minimize flood damage by elimination of vegetation, mainly Tamaris, which obstructed the sections of the wadi. These major cleaning works have modified the morphology of the wadi, since it has undergone a widening of the minor bed, between 20 and 80 m, an identification of the major bed (between 100 and 200m), and also a diking of the banks in order to increase the transit capacity of the evacuated flows [19]. Limits of protectives banks dikes will be shown in all flood map results.

TELEMAC-2D requires two additional physical parameters specific to each application depending on the geometry and physical flow phenomena. These two parameters describe the frictional force and the turbulence conditions [20]. The most influential setting parameter is the bottom friction coefficient, which reflects the roughness of the terrain. In our case, the Medjerda River has been divided into 5 zones, according to the land use, for which a Strickler coefficient value will be applied.

The calibration phase consists in reproducing as faithfully as possible the propagation of a flood in the wadi, by adjusting certain parameters such as the roughness of the ground (Strickler coefficient in our case). The results obtained with this simulation are compared to the gauging measurements carried out by the CRDA in 2019 (Table 3), this gauging has the advantage of corresponding to the configuration of the bed after the CRDA's cleanings. It should be noted that the results of our simulations validated the roughness coefficients chosen.

Table 3 Comparison of flow and water level in meters relative to sea level (general leveling of Tunisia)

	Flow rate (m³/s)	Water level (msl)
Gauging result	345	124.79
Result of the modelling	345	124.82

Thus, a well-calibrated bed roughness coefficient allows for a model that is very close to reality. For our case study, the values chosen are the following (Figure 5):

1) Open minor bed (without vegetation): 0.033 s/m⅓
2) Average bed occupied by tamarix: 0.10 s/m⅓
3) Average bed depth: 0.04 s/m⅓
4) Major bed (agricultural area): 0.06 s/m⅓
5) Major bed (urban area): 0.2 s/m⅓

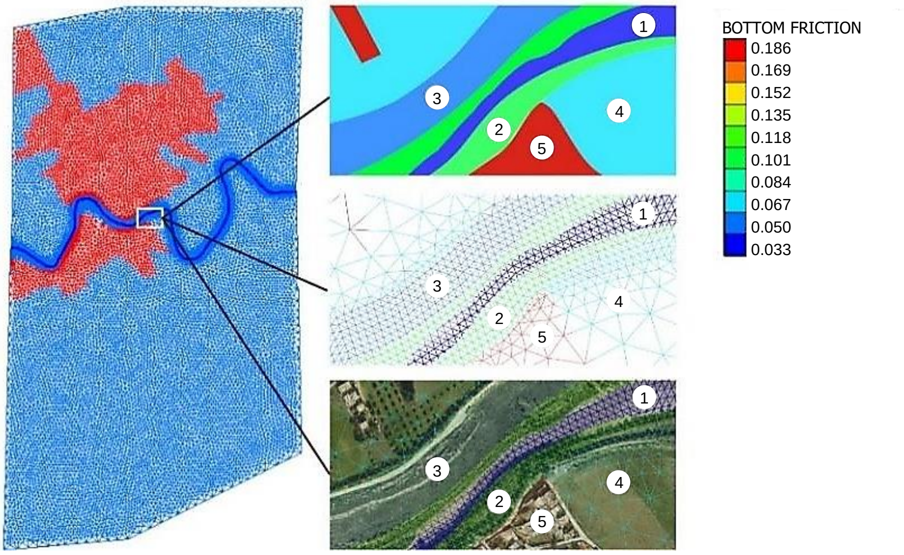

Figure 5 Distribution of the roughness coefficient according to land use

5. Results and analysis

The simulation results are transmitted from Blue Kenue to QGIS. This combination allows for a descriptive overview more adherent to reality. The water level layers are superimposed on the orthophoto image, the intersection between the delimitation of the flooded areas and the boundaries of the different land use components allows for a flood risk analysis. We use the sel2asc.py python script to read the triangulation from the TELEMAC-2D output file, and create a gridded DEM file of the maximum water depth output variable using specified grid spacing [21].

Before simulating floods with different return periods, we decided to carry out flood simulations under historical conditions. There was no flooding recorded after the cleaning work carried out in 2015, but to better visualise the improvements in flood protection brought about by the cleaning works, a comparison was made between the floods observed in 2003, and those simulated for the same event in the current state after completion of the cleaning works (Figure 6).

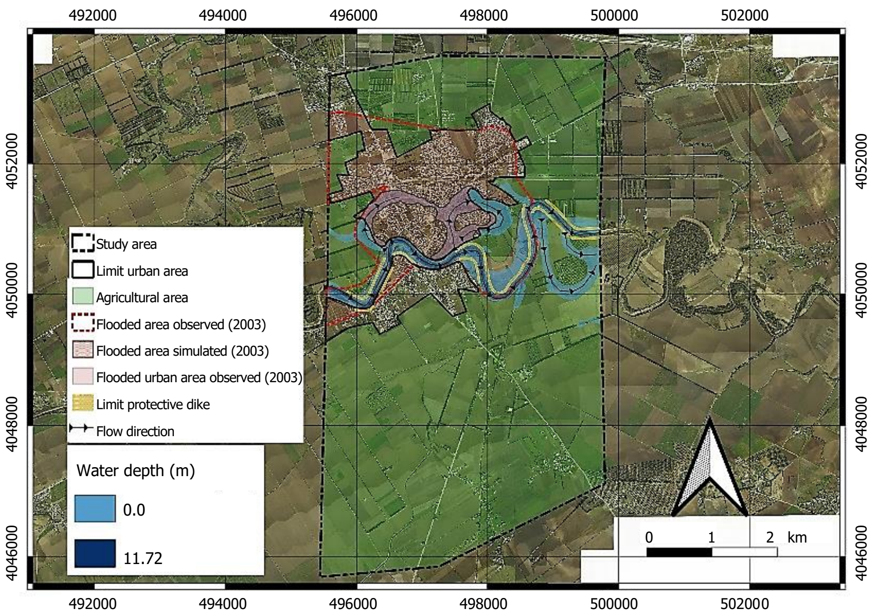

Figure 6 Comparison between simulated and observed flooded area (2003)

The limits of the flooded areas observed in 2003 in the town of Boussalem were collected from the Tunisian Ministry of Agriculture. This delimitation focused solely on the urban areas near the Medjerda. Observations show that the area flooded in 2003 was 413 ha, i.e. 74% of the town was flooded. Simulations carried out by reproducing the same 2003 flood event (flow hydrograph in m³/s on Figure 3) show an area of 83 ha, i.e. 15% of the town was flooded. From this comparison we conclude that cleaning works has reduced the area flooded in urban areas by 59%.

For the 5-year return period flood (Figure 7), it can be seen that the flooding affects the middle bed, which is mainly used by farmers, precisely on the strip bordering the left bank. The flooded areas reach a surface area of about one hundred hectares in the agricultural zone, and about ten hectares in the urban zone. The overflows follow the flow typology, they are linear in accordance with the course of the watercourse. There is no indication of a lateral extension of the flood wave. The propagation in the urban area and the agricultural plain is limited. The flow widens before the town by about 200 m, then decreases by about 100 m at the town (due to the existing protective embankments), and finally, in the lower part, it widens again by 300 m.

In our study area, the wadi and its tributaries form deep meanders. For floods with a return period of 10 and 20 years (Figure 8), the flood wave propagates vertically and exceptionally overflows outside the trench formed by the wadi bed to flood the old abandoned meanders on the left bank, which are no longer part of the wadi bed (vertical flood waves are showed in maps by arrows of flood direction which are perpendicularly to the horizontal direction of wave in the wadi). These meanders are progressively exploited by farmers or invaded by the urban extensions of the town of Boussalem. The flooded areas are significant, varying from 41 to 168 hectares in the urban area, and from 140 to 355 hectares in the agricultural area. This creates a high risk for the left bank of the wadi where 90% of overflow occurs. The areas bordering the right bank remain protected by protective banks dikes, especially the urban area (urban area remaining protected is area located in black outline polygon (limit urban area) and out of flooded urban area indicated by red polygon in all flood map results.

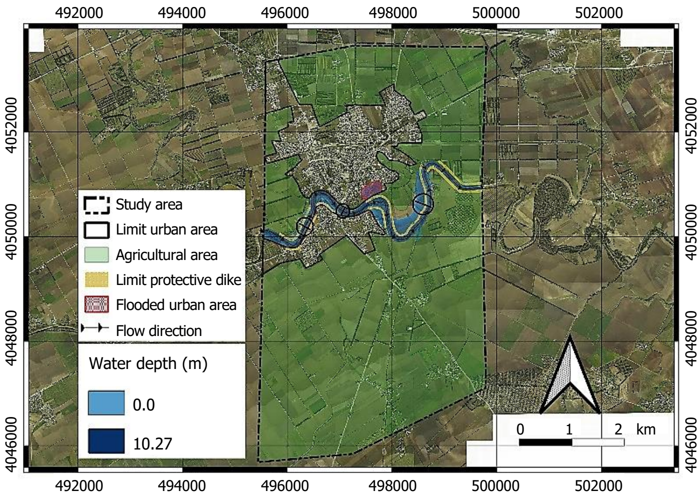

Figure 7 5-year return period flooding

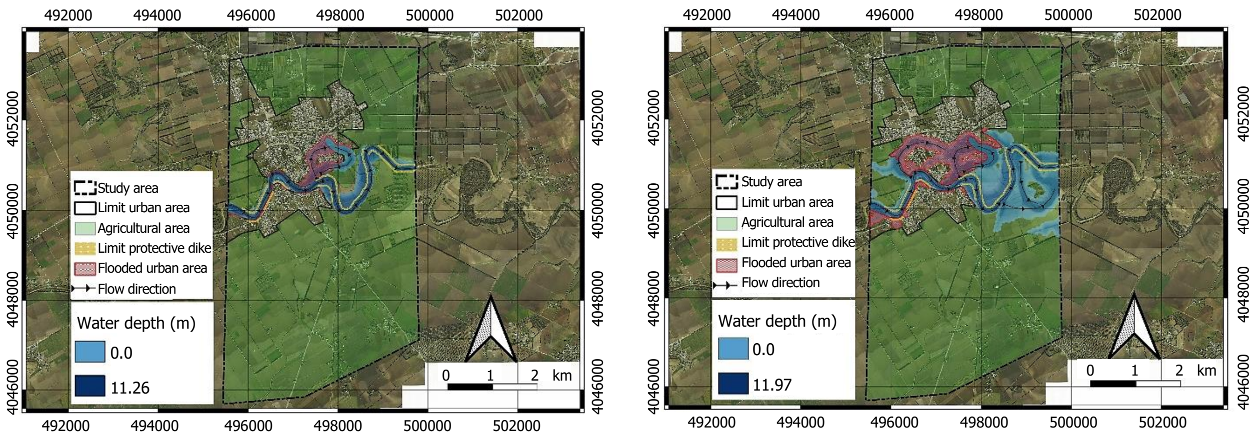

Figure 8 Flood map for 10-and 20-year return periods

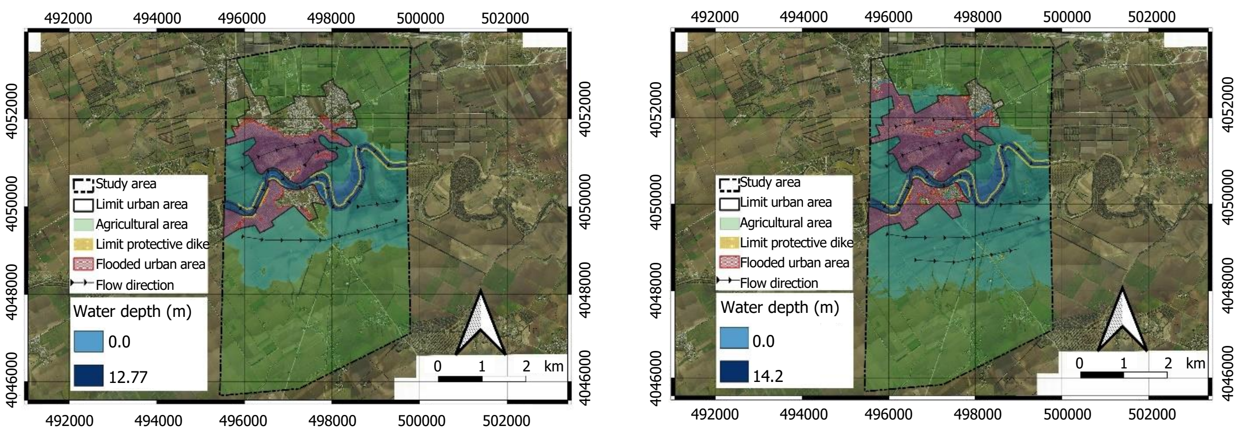

Figure 9 Flood map for 50- and 100-year return periods

In the case of extremely exceptional floods with a return period of 50 and 100 years (Figure 9), the flood wave becomes devastating and affects both banks in parallel. All the neighbouring agricultural plots in the major bed of the wadi, including the houses, are invaded by the overflowing water. The low-lying areas in the town of Bousselem are also flooded. In the lower area outside the town, there is also a spreading of the flood field. The flow extends over a very wide area, up to more than five kilometres for the 100-year flood.

The flood risk maps provided indications of areas at risk of flooding for a return period of 5, 10, 20, 50 and 100 years, covering 98 ha, 181 ha, 484 ha, 1087 ha and 1697 ha respectively.

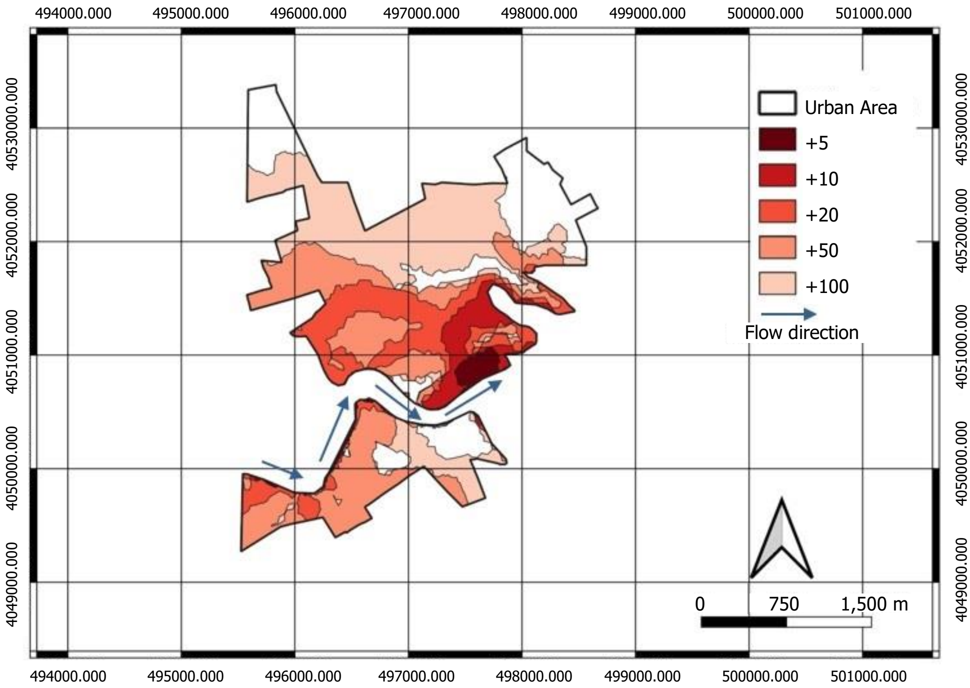

Figure 10 Flood risk in the city of Boussalem at different return periods

The boundaries of the flooded area in the Boussalem city have been estimated according to the extent of the maximum water level of the floods corresponding to each event (Figure 10). Figure 11 shows a spatial distribution of the flooded areas according to the events with different return periods.

In order to analyse the flood risk maps, two risk classes are defined. The first one is a medium to low risk class, where the urban area flooded is less than 20% and where the mobility of the inhabitants remains easy, and the second class is a high risk class, where the urban area flooded is more than 20% and where mobility is more difficult and access to the different infrastructures and services is more complex [22].

- Events with a return period of 5 and 10 years belong to the first risk class. The areas flooded represent 2% and 8% of the territory respectively (Figure 11).
- Events with a return period of 20, 50 and 100 years belong to the second risk class. The flooded areas represent respectively 30%, 50% and 86% for (Figure 11).

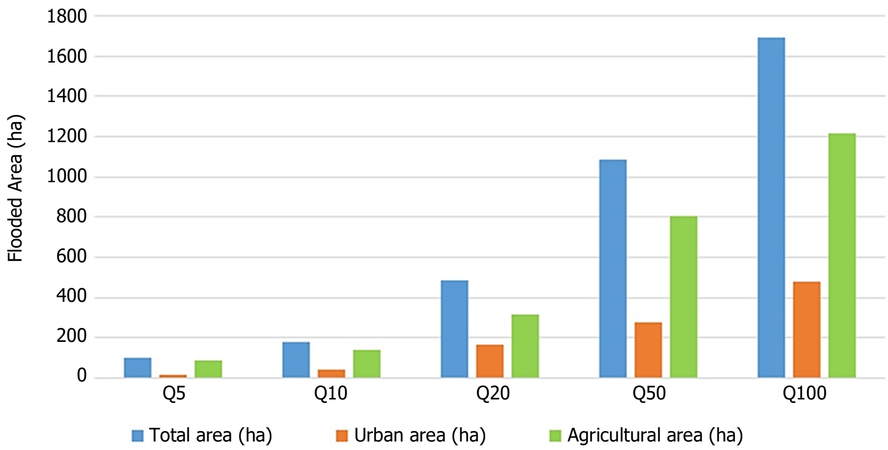

Figure 11 Flooded areas for different return periods

Despite the implementation of several protection and cleaning measures, there is still a high risk of flooding. This is linked to the fact that the bed of the Oued Medjerda undergoes excessive vegetation development and progressive silting [23], particularly in the town of Boussalem, given the low-lying location of its area. This makes it necessary to look for a relevant solution such as the execution of a total diversion outside the city.

6. Conclusions

This study aimed at assessing the flood risk on the Medjerda River crossing at the level of the city of Boussalem. The study area is characterised by very winding rivers with predominantly Agricultural floodplains, embanked infrastructure and high human occupation near the rivers. A two-dimensional 2D modelling approach was carried out using TELEMAC-2D software for flood modelling for different return periods. The floodplain boundary was estimated based on the extent of the maximum flood heights.

A comparison was realised between flood event observed in 2003 and those simulated in the same hydraulic conditions, before and after cleaning works. We conclude that cleaning works have reduced flood in urban areas by 59%.

The flood risk maps provided indications of areas at risk of flooding for a return period of 5, 10, 20, 50 and 100 years, covering 98 ha, 181 ha, 484 ha, 1087 ha and 1697 ha respectively. Priority was given to the spatial distribution of flooding between agricultural and urban areas. The results indicate that the flooded areas in the city represent respectively 2%, 8%, 30%, 50% and 86% for the 5, 10, 20, 50 and 100 years return period events. 20, 50 and 100 years return period events shows the existence of a strong risk of danger for these events in spite of the various protection and drainage schemes carried out by the Tunisian government.

These results can be used as a preliminary information guide for setting up warning systems, land-use planning and policy development for safety investment decisions. In addition, the model can be used to simulate floods in real time in order to map the flooded areas and, as a result, decide on the fighting strategy and adopt relief measures.

7. Acknowledgement

The data were provided by the Ministry of Agriculture, Water Resources and Fisheries, whom we warmly thank.

8. Reference

[1] Gharbi M, Soualmia A, Dartus D, Masbernat L. Floods effects on rivers morphological changes application to the Medjerda River in Tunisia. J Hydrol Hydromech. 2016;64:56-66.

[2] Romdhane H, Soualmia A, Talbi S. Simulations of possible floods linked to the wadi banks widening in the Somaa city at Cap Bon-Tunisia. J Mater Environ Sci. 2020;11(10):1658-66.

[3] Halwatura D, Najim MMM. Application of the HEC-HMS model for runoff simulation in a tropical catchment. Environ Model Softw. 2013;46:155-62.

[4] Liu Z, Merwade V, Jafarzadegan K. Investigating the role of model structure and surface roughness in generating flood inundation extents using one- and two-dimensional hydraulic models. J Flood Risk Manag. 2019;12(1):1-19.

[5] Horritta MS, Batels PD. Evaluation of 1D and 2D numerical models for predicting river flood inundation. J Hydrol. 2002;268(1-4):87-99.

[6] Villaret V, Hervouet JM. Cross-comparison of different approaches for sediment transport by bed load and suspension. Ninth National Days Civil Engineering - Coastal Engineering; 2006 Sep 12-14; Brest, France. France: National Laboratory of Hydraulics and Environment; 2006. p. 463-70.

[7] Mattic O. Telemac2d Reference Manual. Version v8p0. France: Electricite de France; 2020.

[8] Pavlíček M, Bruland O. Numerical modelling of flash flood event in steep river using Telemac 2D and Sisyphe. XXVI Telemac & Mascaret User Conference; 2019 Oct 16-17; Toulouse, France. France: Hydraulic Engineering Repository; 2019. p. 1-7.

[9] Periáñez R. Chemical and oil spill rapid response modelling in the Strait of Gibraltar- Alborán Sea. Ecol Modell. 2007;207(2-4):210-22.

[10] Forster A, Costi J, Marques WC, Wormsbecher AG, Bendô ARR. Application of the TELEMAC- 2D model in the fluvial hydrodynamics simulation and reproduction of flood patterns. Defect Diffus Forum. 2019;396:187-96.

[11] Rodier JA, Colombani J, Claude J, Kallel R. The Medjerda watershed. Monograph. Hydrology. Tunisia: ORSTOM; 1981.

[12] Sommer. Digital Atlas of Jandouba Governorate. Tunisia: Ministry of equipment and housing, Directorate general of regional planning; 2012.

[13] Paquier A, Mignot E, Bazin, PH. From hydraulic modelling to urban flood risk. Procedia Eng. 2015;115:37-44.

[14] Villaret V, Hervouet JM, Kopmann R, Merkel U, Davies AG. Morphodynamic modeling using the Telemac finite-element system. Comput Geosci. 2013;53:105-13.

[15] Li Z, Liu J, Mei C, Shao W, Wang H, Yan D. Comparative analysis of building representations in TELEMAC-2D for flood inundation in idealized urban districts. Water. 2019;11:1840.

[16] Japan International Cooperation Agency (JICA). Report of the study on integrated basin management focused on the regulation of floods in the Medjerda Basin. Tunisia: Ministry of agriculture, Water Resources and Fisheries, Directorate general of Dams and Major Hydraulic Works; 2018.

[17] SCET-Tunisia, Artelia Echirolles. Water storage and flood protection program, study of measures relating to flood protection in the Medjerda watershed. Tunisia: Ministry of Agriculture, Water Resources and Fisheries, Directorate general of Dams and Major Hydraulic Works; 2020.

[18] Romdhane H, Soualmia A, Talbi S, Gharbi M. Curage de la Medjerda. The International Conference and Demonstration on Advanced Geospatial Science and Technology; 2016 Oct 16-18; Tunis, Tunisia. Tunisia: Teangeo; 2016.

[19] Hammami S, Romdhane H, Soualmia A, Kourta A. 1D/2D coupling model to assess the impact of dredging works on the Medjerda River floods, Tunisia. J Mater Environ Sci. 2022;13(7):825-39.

[20] Coldren C, Asadi A, Cleveland T, Rainwater K. Coupling EDYS and TELEMAC-2D for ecohydrological and Hydrodynamic simulation of San Antonio Bay. Lubbock: Texas Tech University; 2020.

[21] Prodanovic P. QGIS as a pre- and post-processor for TELEMAC: mesh generation and output visualization. XXII Telemac & Mascaret User Conference; 2015 Oct 15-16; Warrington, UK. UK: Hydraulic Engineering Repository; 2015. p. 83-90.

[22] CEREMA. Repository national of vulnerability to floods, ministry of environment, energy and sea. France: European flood risk forecasting center; 2018.

[23] Morri M, Soualmia A. Modeling the impact of riparian vegetation on flow structure and bed sediment distribution in rivers. Arch Hydroengineering Environ Mech. 2019;66(3-4):59-75.