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A GIS-based flood risk assessment and mapping of Er-Rich village (High Atlas of Midelt, Morocco)

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Abstract

Floods are among most destructive natural hazards worldwide. Morocco is not spared from these phenomena; each year socioeconomically losses are recorded in several regions. At the end of November 2014, the Er-Rich village (Central high Atlas of Morocco) knew a heavy rainfall event that had significant flood impacts because of its localization at low topography and at the natural bed of the Ziz River. These floods have been exacerbated by the reduction of floodplain by the uncontrolled urban and agricultural development around the river. This study presents a methodology for the simulation of floods of the Ziz river through three retourn periods (10, 50, and 100 years) in order to identify floods areas and maximum water high that can reach. The studied segment of the Ziz river starts from the north irrigated lands of the village up to the south irrigated lands. The inundation simulation was conducted using hydrodynamic program HEC-GeoRAS based on DEM and land uses data. The obtained results has identified several areas of high flood risk witch should be helpful for future land use planning and for Rich citizens security.

1. Introduction

Floods are considered among the most important natural disasters, which present a growing threat to the world more than other natural hazard.

Today, floods are probably the most devastating, widespread and frequent disasters [1, 2]. Some of these disasters result from periodic natural phenomena such as the monsoon or el niño, others are the result of particular circumstances (cyclones, typhoons, violent storms) and are aggravated by the climatic disturbances.

In the future, according to climate changes and human activities in the world, floods are expected to be more frequent and more disastrous [3, 4].

According to the international [5], 2,470 floods have occurred in the world during the period (1999 and 2009). 147,457 people lost their lives and the damage was estimated at US $ 372.5 billion.

Like other regions bordering the Mediterranean Sea, Morocco is also affected by violent floods, causing extended damage to the populations and infrastructures [1,7]. It is one of the most vulnerable countries to these natural hazards in the Mediterranean basin [6,8]

During the period (1999-2009), fifteen major floods were observed, which killed 1068 people and affected more than 146,400 people. The damage caused by the floods was considerable and damaged several infrastructures. (State Secretariat at the Ministry of Energy, Mines, Water and Environment for Water and Environment, 2008, flood risk, studies and measures)

At the end of November 2014, the central High Atlas of Morocco was hit by extreme weather conditions, which resulted in catastrophic floods. The Er-Rich village was the most affected because of its location, exposed to flood risk of the Ziz river.

At the origin of these floods, a heavy rainfall event with precipitation that reached more than 120mm in 24 hours [9]. The changes made around the river, including the occupation of its riverbed by agricultural activities and building, contributed largely to flood risks. This situation highlights the urgency of conducting flood risk studies to prevent and avoid catastrophic consequences in the future.
For this purpose, the main objective of this work is the mapping the flood areas on either side of Ziz river, upstream of the Foum Zaabel hydrometric station, which is occupied by dwellings and cultivated fields on the riverbed; as well as the study of the probabilities of submersion of the national road connecting Midelt to Errachidia. The approach used will consist of a simulation of the extreme flows along the valley and the submersion spatialization according to the frequency of these flows.

1.1. *Study area*
The Er-Rich village is located in the southern flank of the High Atlas central. It belongs to the province of Midelt, And is surrounded by Guers Tiaallaline, Sidi Aayad and En-Nzala rural municipalities, (Figure 1). Currently, this village is become a veritable pole of business attraction of the whole of the surrounding municipalities. Indeed, Its population increased from 20155 in 2004 to 25992 in 2014 with a growth rate of 2.58%.

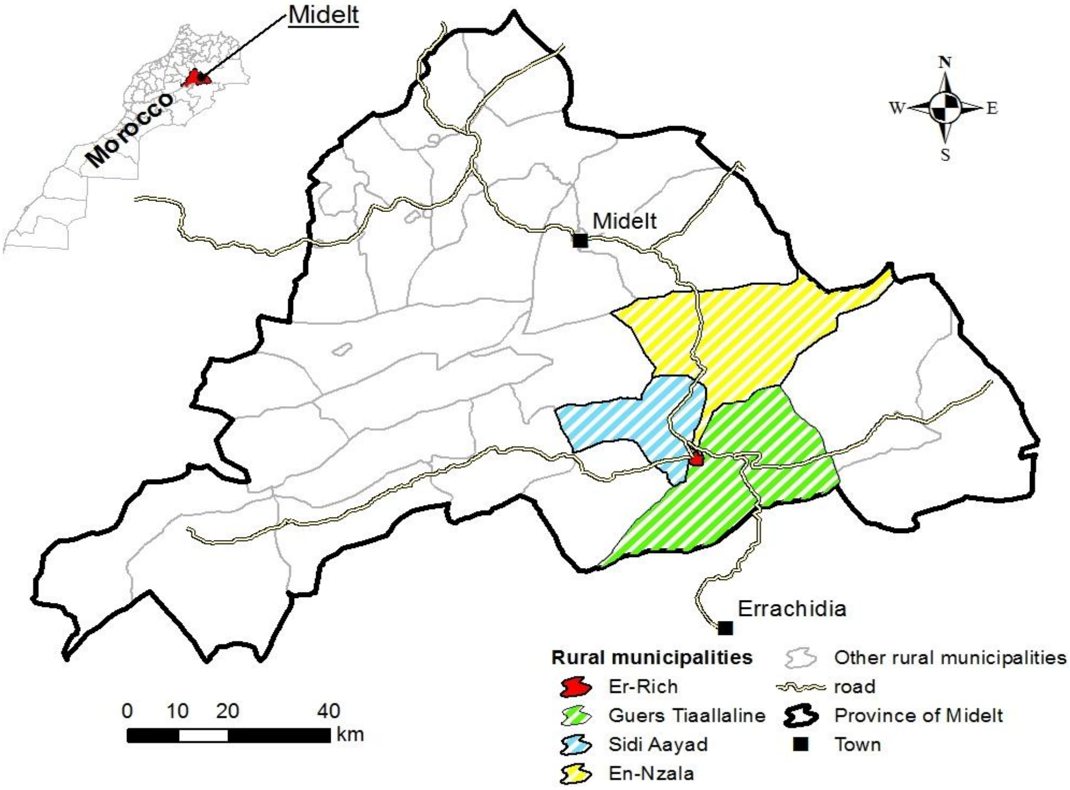

Figure 1: Administrative situation of the study area

The Ziz river valley is a 250 Kilometer-long ribbon of irrigated cultural lands that winds out of the eastern Hight Atlas Mountains and drains approximately 14400 square kilometers [10].
The Ziz watershed above the Foum Zaabel station have about 3964 km^2 and its fairly compact, with a compactness coefficient of 1.3 and a hydrographic network fairly dense and well branched. The slopes of the sides and tributaries are relatively important: 1 to 30 degrees in general, but can reach by places 60 to 70°, reflecting a low duration of concentration of runoff in the tributaries of the Ziz river (figure 2).

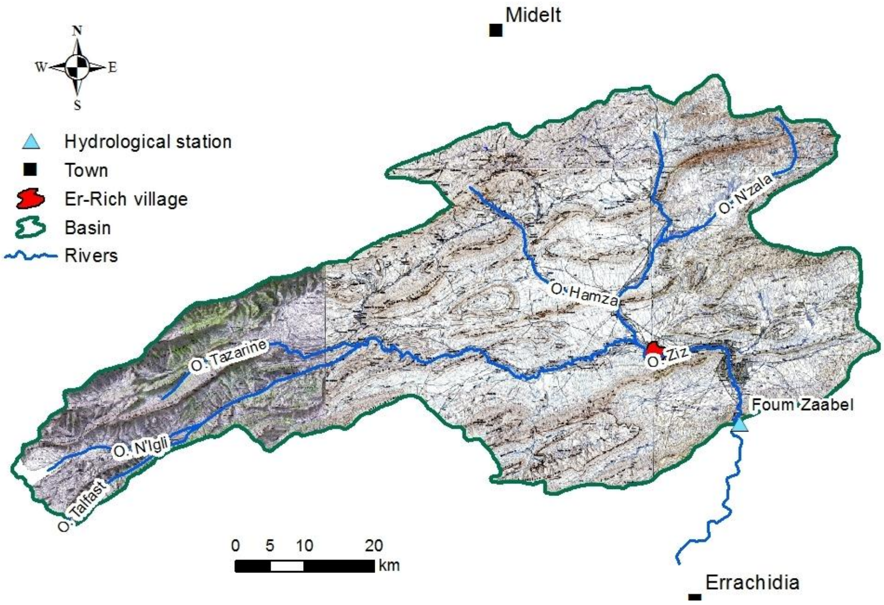

Figure 2: hydrological situation of the study area

The climate of this watershed is characterized by a high variability, the precipitations vary in intensity and in their geographical distributions following altitudes, The rainfall monthly averages and highlights a rainy period ranging from September to May, which encompasses almost all of the precipitation with the three peaks, the stronger in October and the two other means in February and April [11, 12].
According to the inter-annual regime, the rainfall vary from a few tens of mm to year severely dry at more than 500 mm in year exceptionally wet [13]. The number of rainy days is also very variable. It is 30 to 40 days per year in the mountains areas of the High Atlas. The weakness of the number of days of rain per year led to a regime of very erratic surface waters with flows in the form of brief and violent floods and perennial waters sometimes non-existent.
The geological formations of the Ziz high basin are dominated by limestone and marly limestone-of Mesozoic age in the form of elongated Anticlines, treble, and asymmetric, interrupted by wide synclinal to allure of cups and to fill constituted by conglomerates, alluvial deposits, limestones, lacustrine, sands and silts [14-19].
The land use at the right of the study area consists of residential districts, public establishments, rural habitations and irrigated fields. This land use is given in the table below in areas.

Table 1 : Land use in the study area

LAND USE	Ha
Residential districts and public establishments	179
Rural habitations	20.48
Irrigated fields	626.4

The selected segment of the Ziz river that crosses the boundaries of the Er-Rich village, is the one that starts from the irrigated fields on the north of the village through the Rich Laqdim district, the 20 August district, the stadium, district Massira 2, up to the Boulili district and the irrigated fields south (Figure 3).
The river bed is characterized by the presence of stony materials and sometimes gravelly and sandy loam soils [20-23].

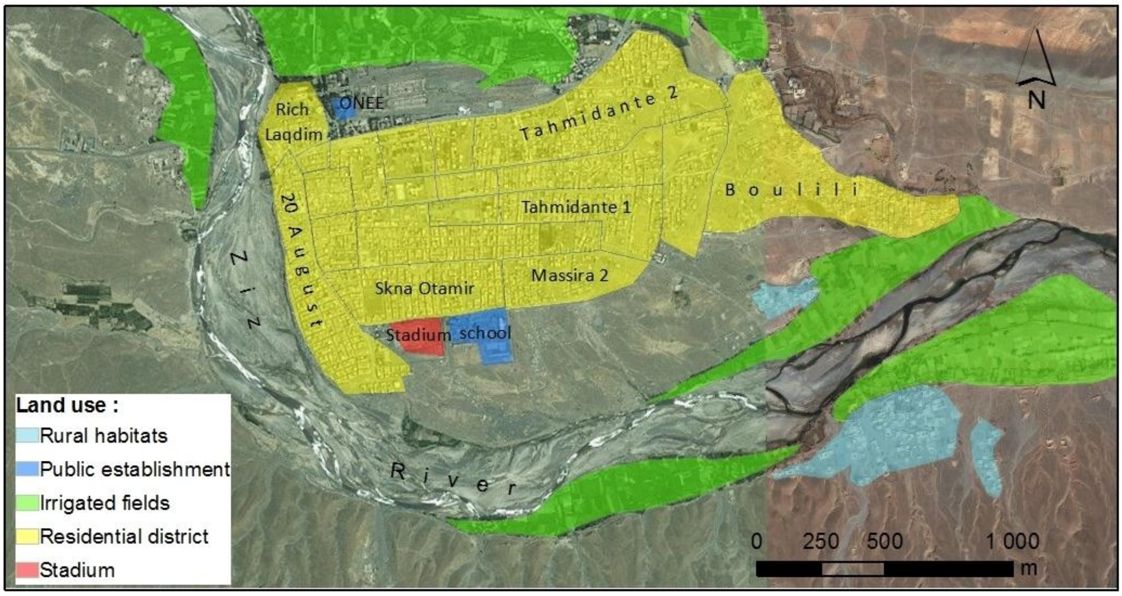

Figure 3: Land use around the studied section

2. Materials and methods

This study is based on the hydraulic modeling with gradually flows varied, and free surface under the 1D model of Saint-Venant, known as HEC-RAS (Hydrologic Engineering Center - River Analysis System), which is developed by " Hydrologic Engineering Center of the U.S. Army Corps of Engineers " for the floods simulation [24-26]. This software has already proved as very successful for this type of study, and many universities and companies consider it as the first-aid tool [27]. We have the version (HEC-RAS 4.2.0) available free on the official HEC-RAS website. Another main tool used in the framework of this study is the ArcGIS of the Institute ESRI (Environmental Systems Research Institute) through the extension HEC-GeoRAS, intended for the preparation of data and their export to the HEC-RAS as well as the exploitation of the simulation results in a GIS environment [28-31]. The organizational chart below (figure 4) illustrates the broad lines of this work.

The main data used for this work is the high-precision digital terrain model (DTM), which is generated from a Digital Elevation Model, Shuttle Radar Topography Mission (30m DEM SRTM), thus offering great potential in terms of accuracy and detail.

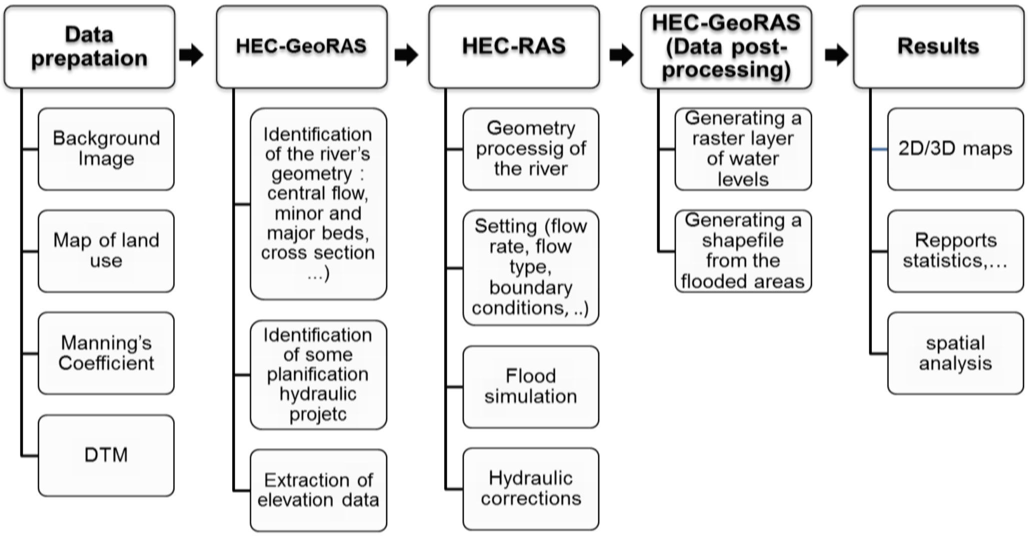

Figure 4: Organization chart adopted

Then we proceeded to convert the Digital Terrain Model (DTM) to Triangulated Irregular Network (TIN) ; it is a format developed by ESRI, much more used with HEC-RAS in the hydraulic modeling study; Then, the algorithms used by either HEC-GEORAS or HEC-RAS reveal a much higher processing speed as much as the Grids. That's the reason the HEC-GeoRas user manual recommends the TINs.

Topographic maps are also used to digitize and verify some features such as streams, banks, etc. It was necessary to verify that the geographic coordinate system is a system metric: Lambert Conformal Conic (Morocco Zone I).

This is extremely important for not having anomalies after exporting geometry to Hec-Ras. The first fundamental element is to identify the geometry of the river, using the HEC-GeoRas extension which allows the following entities to be digitized.

- Cross section: which determine the elevation of the flow surface and its slope and the floodplain topography. 33 profiles well distributed along the section studied were generated. These profiles are perpendicular to the flow direction, they not intersect between them, they intersect the entire alluvial plain and take each geomorphological variations of the floodplain,
- The hydrographic network: generated from the MNT, taking account the natural watercourse,
- The bank lines: generated also from the MNT. They allow to define the channel flow ;

The Flow Path centerlines: which envelop the channel flow and lines banks, allowing the software to calculate the distances between each profile across and its neighbor immediately downstream (Figure 5).

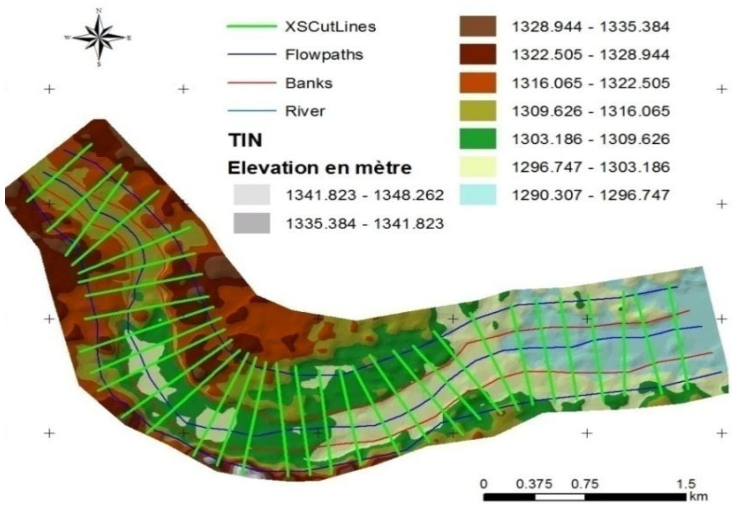

Figure 5: Studied segment geometry

The second fundamental element is the Manning coefficient which allows us to have a model closest to reality. The values of this coefficient were defined for each homogeneous area of the section studied. The values adopted are based on our field observations: 0.04 for the riverbanks and 0.055 for the natural bed in the sections where the river is shallow with a gravelly and sandy bottom, and presence of little riparian vegetation.
0.035 for the iverbanks and 0.055 for the natural bed in the sections, where the river is shallow with gravelly and sandy bottom, with the presence of cultivated fields bordering.
The model takes into account the change in the roughness between the banks and the bottom of the river, with a total of two roughnesses for each cross section.

Table 2 : values of the Manning's coefficient assigned to different sections of the segment studied

Shores with some riparian vegetation	0.04
Natural beds	0.055
Shores with presence of cultivated fields bordering	0.035

The third fundamental element we work with is the flood flows and boundary conditions. In this study, we exploited the maximum annual flows adjusted to the right of the Foum Zaabel station (figure 2), located at 20 km in the south of the section studied. The flow rates are adjusted by various statistical laws and the incomplete gamma law which is retained appears to be the most adequate [32].

Table 3 : Adjustment of the maximum annual flow rates by the gamma law (at the right of the Foum Zaabel station).

Station	Surface of the basin (km^2)	River	Q10 (m^3/s)	Q50 (m^3/s)	Q100 (m^3/s)
Foum Zaabel	3964	Ziz	1452	2587	3084

In order to evaluate the flows of the floods in the studied section, we used the regional formula, using the flows measured and adjusted at the Foum Zaabel station. The formula used is of the following form [33]:

$$\boxed{Q_T = a(T) \times A^b} \quad \text{equation (1)}$$

With:

QT : Flow rate in m^3/s corresponding to the millennium return period.
A : area of the watershed (in km2).
b : 1
a(T) : Calculated parameter according to the importance of the watershed.

The following table presents the variation of the parameter a(T) of the regional formula for the section studied.

Table 4 : parameter a(T) of the regional formula.

Return period t in years	a(T)
10	0.3663
50	0.6526
100	0.7780

The calculated peak flow rates are given in the table below.

Table 5 : Simulated peak flows at the right of the studied segment

Investigated portion	Surface of the BV (km^2)	Oued	Q10 (m^3/s)	Q50 (m^3/s)	Q100 (m^3/s)
	3147	Ziz	1153	2054	2448

These flows obtained at the different return periods will be used for the simulation of the model.

3. Results and discussion

3.1. *Floodplains and heights of maximum waters obtained*

The result of the simulation shows that the flood surface grows, around the river beds, since the decadal flood up to the centennial flood level (Table 6). The simulation of the decadal flood gives a flood area of 348.43 Ha with heights of water can reach till 7.19 m. The simulation of the cinquantennale flood gives a flood area of 388.72 Ha with heights of water can reach till 8.14 m. The simulation of the centennial flood gives a flood area of 589.24 Ha with heights of water can reach till 8.42 m. This result allows a mapping of the flood area by comparing the result of the hydraulic model with the topography of the study area, and consequently the visualization of the stream overflows on its banks (Ziz river) and riparian area.

Table 6 : Comparison of the water elevation and the flooded areas, for the three simulated floods.

Flood	Height of water (m)	Flooded areas (Ha)
Decadal	7.19	348.43
Cinquantennal	8.14	388.72
Centennial	8.42	589.24

3.2. *Spatial Analysis*

The crossing of the water level obtained with different return periods with the land use map collects more useful information to the management of risk of flooding. This has enabled us to establish 3 maps of threatened areas.

The simulation of the lateral extension of these floods highlights significant overflows of rivers on its banks; in fact, in the case of a decennial flood, the flood zone covers an area of 348.43 Ha: 260.30 Ha of the floodplain, 27.72 Ha of agricultural land located in the north of the center, 15.39 Ha of agricultural land located in the south of the center, 0.89 Ha of the Boulili quarter and 42.79 Ha of unoccupied land (Figure 6).

In the case of a Cinquantennal flood, the flood zone covers an area of 388.72 Ha, distributed as follows: 256.08 Ha of the floodplain, 42.44 Ha of agricultural land located in the north of the centre, 19.10 Ha of land farm located in the south of the center, 2.28 Ha of the Boulili quarter and 68.82 Ha of unoccupied land (Figure 7).

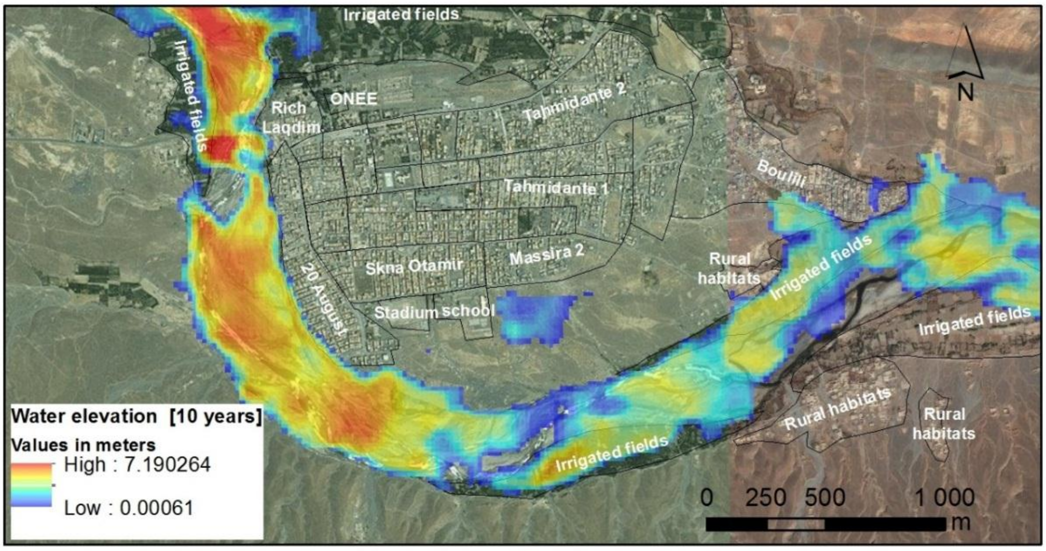

Figure 6: Decadal flood simulation (10 years)

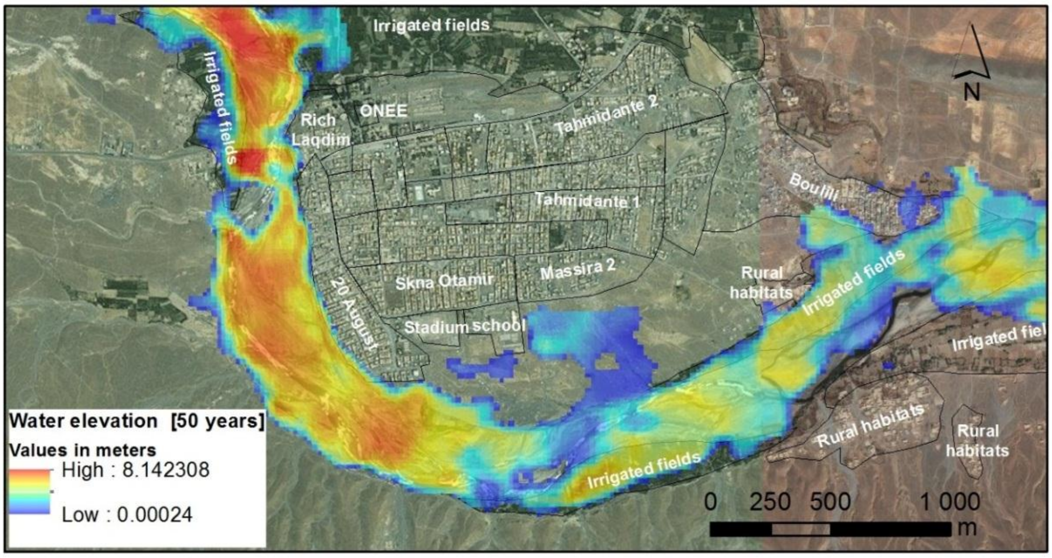

Figure 7: Cinquantennale flood simulation (50 years)

In the case of a Centennial, the flood zone covers an area of 589.24 Ha: 446.25 Ha of the floodplain, 45.20 Ha of agricultural land located in the north of the center, 22.15 Ha of agricultural land situated in the south of the entre, 2.68 Ha of residential area Aug. 20 and Rich Laqdim, 3.37 Ha of the Boulili quarter area and 69.58 Ha of unoccupied land (Figure 8).

These figures can be used to highlight areas at risk in order to propose development plans to protect some areas or prohibit construction in others.

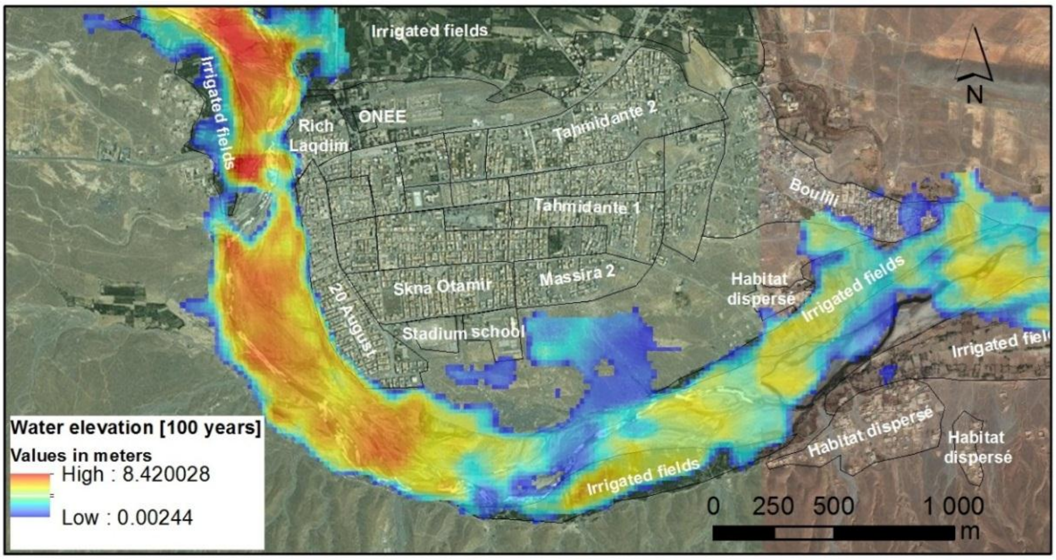

Figure 8: Centennial flood simulation (100 years)

3.3. *Profiles across*

This option to display the results by profile across, allows you to acquire the maximum detail to each point chosen in the studied section. The cross sections presented by the figures below, allow you to view the areas where there is a maximum of overflow of the river on its banks and riparian areas.

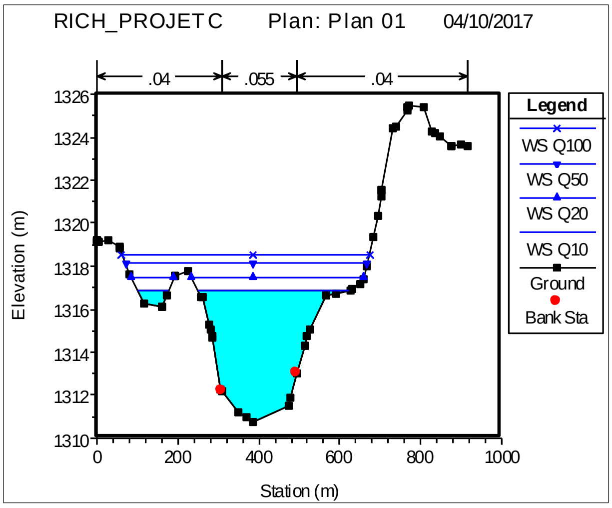

Figure 9: Cross section at the right of irrigated plots North

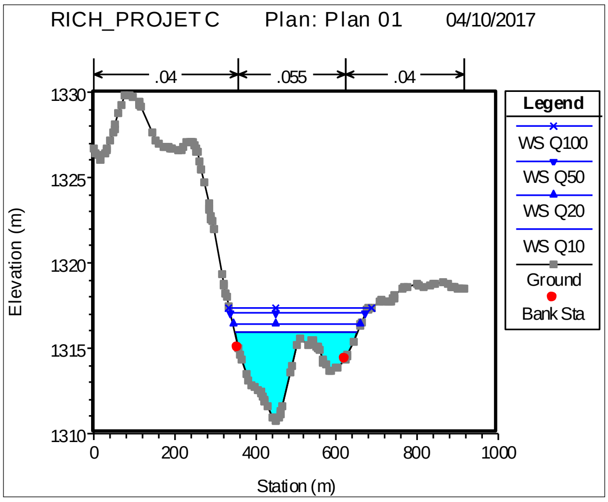

Figure 10: Cross section at the right of the District 20 August

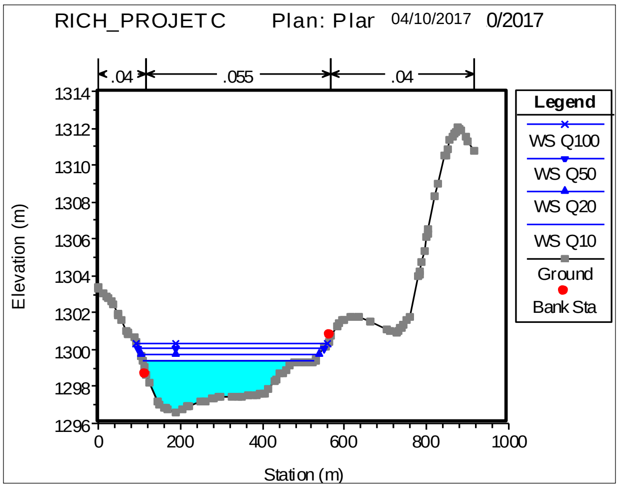

Figure 11: Cross section at the right of the neighborhood Boulili and irrigated plots South

Figure 12: Flood of september 2006 at the right of the Er-Rich centre

3.4 *Flow velocity*

The figure n° 13 shows the variation in the water flow rate at the center, left and right of the Ziz river for three return periods. We observe almost the same pace for all the water levels with three important peaks in the following sections [1100-1200 m], [2900-3200 m] and [4800-5000 m], where the river is more cashed, and so the flow sections are smaller and hence the increase in speed.

As for water heights, these are maximum velocities reached during the simulation, and therefore not necessarily reached at the same time.

In order to validate this result, a comparison was made between the simulated and the measured flows at the right of the studied section. This comparison is an essential step in hydraulic modeling, because it determines the quality and validity of the model results. Indeed, it consists to valid the retained parameters during the calibration phase of the model. In this case, the analysis of the existing documents identified the main floods that occurred in the study area. Given the number of recorded information and its importance, the event selected for the calibration and validation of the model is that of september 2006, wich generated some damage on the center.

The maximum flow rate measured during this event is 1122m^3/s which is similar to the decadal flow rate obtained in the hydraulic calculation. This flow gave a maximum height of water around 6.95m which will allow us to confirm the fiability of the model result (table 6). The figure 14 bellow shows the simulated and measured hight water level at the section studied.

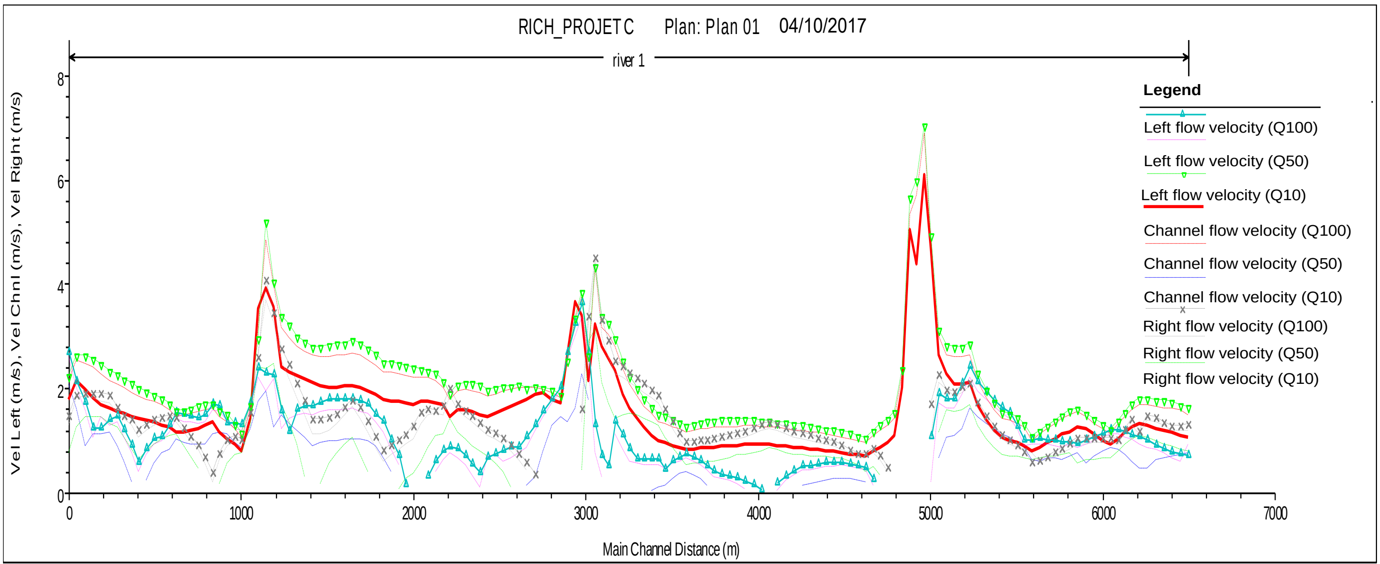

Figure 13: Variation of the flow velocity along the studied segment.

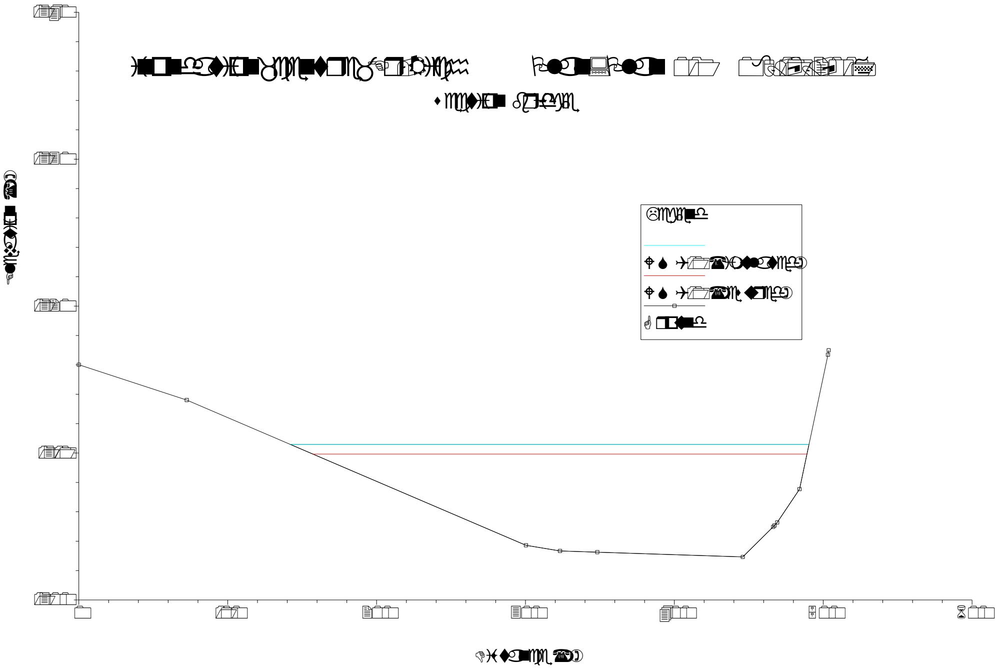

Figure 14: Variation of the flow velocity along the studied segment.

Conclusion

The watershed of the upper Ziz, presents a continuing threat of flooding related to the center of Er-Rich. The climatic and hydro-geomorphological context of this watershed favors the generation of violent floods, characterized by high speeds and relatively short rise times.

This hydraulic study gave a lot of information about the flood phenomenon, the water levels, the delimitation of flood areas and the flow velocities.

Based on the obtained results, three black spots were identified, they present a high risk of overflow of the river Ziz on agricultural activities and riverside districts. The northern and southern irrigated fields as well as of August 20 districts, and Rich Boulili laqdim are the most affected .

Furthermore, attention should be drawn to the human and economic costs of flood damage with the need to develop plans for land that preserve the property of citizens and their own security. A firm and respected legislation is required for the preservation of public water resources for dealing with recurring injuries flooding of the river.

However, the application of this method in this study allowed us to draw certain information, like :

- the precisions made on the floodplain maps remain relative and it is only valid to map the river section concerned by the present study ;
- the methodology used allows to map flood area risk at even more detailed scales when, for example, we are interested to studied a specific site;
- the flood risk map obtained is valid only for the date of its realization. Indeed, the strong anthropization, in particular the progression of constructions in the river banks implies rapid and significant changes in the morphology of the riverbed. The Rapid and increasing of the anthropic occupation can therefore affect and modify in the future the flood areas identified in this study.

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