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Cartography of Flooding Hazard in Semi-Arid Climate: The Case of Tata Valley (South-East of Morocco)

Echogdali FZ[1], Boutaleb S[1]*, Jauregui J[2] and Elmouden A[1]

[1]Laboratory of Applied Geology and Geo-Environment (LAGAGE), Ibn-Zohr University AGADIR, Morocco
[2]Department of Plant Biology and Ecology, University of Sevilla, Spain

Abstract

Reliable estimates of river stream flow and flood zoning maps are needed for water resources management such as flood mitigation, water supply, dam construction and irrigation. The flood hazard caused by Tata River in the Southeast of Morocco Kingdom, is assessed using statistical modeling technique (Weibull), hydraulic modeling with HEC-RAS and the Geographic Information Systems (GIS). Four flood maps for return periods of 20, 50, 100 and 500 years are generated. For the four return periods the maximum depth of water reached by the river and extent of flooding are estimated. For 500 year return period (Q=860 m^3/s), water average depth on the left river (Teghremt) and right one (Tata) is 2.20 m and 3.05 m, respectively. The flood hazard modeling reveals that the flooded zone is more significant out of the left (east) tributary (Teghremt) than out of the right (West) Tata river. Through lateral flood zoning maps, areas that are vulnerable to flooding hazards have been identified. This information is useful in defining the minimum height of flood protection structures such as dikes to protect the area from flooding. The results can be useful for evacuation planning, estimation of damages and post flood recovery efforts.

Keywords: Flood; Flooding hazard; Tata river; HEC-RAS

Introduction

It should be stressed that, during the last few decades, natural hazards have been the cause of the loss of hundreds of thousands of human lives and for damage and mosses of billions of dollars around the world [1]. Just in the period 1974-2003 more than two million people lost their lives due to natural hazards [2]. Flooding caused by storm events becomes a major concern in many parts of the world [3-5]. Most rain, precipitation duration, snowmelt, stream overflowing channels, inadequate drainage systems and the saturation of the soil are the main causes of floods [6]. In arid and semi-arid regions, rainfall usually comes for short durations but with high intensity [7-9].

With more extreme weather patterns predicted in the future, more frequent floods are expected to occur in the world especially in arid regions [10]. This fact has been confirmed in the last decade by a big number of flood events observed for example in Kingdome of Morocco [11]. The flash flood events of 2014 for instance, had heavy consequences: 47 life losses in the Southern provinces and material damage assessed in over 6 billion dirhams (600 million USD), including cut roads, burst dams and power cuts affecting a great part of the population.

In this sense, the elaboration of flood maps and risk prevention plans is of capital interest for decision-making authorities of both territory development and efficient management of onsite crises. Cartography of areas liable to flooding must be based on reliable qualitative and quantitative data (high resolution DEM maps, long period and big number of flash flood events, etc.).

Recently, flood forecasting has greatly improved with the rapid advancement in technology. The availability of high speed computers and high performance software packages provides engineers with an excellent tool to perform flood modelling and simulation. Also, advancement in geographic information system (GIS) and availability of high-resolution digital elevation models (DEMs) have great improvement in flood modeling. Integration between GIS software and hydrologic/hydraulic models can help engineers and planners in investigating the risk of floods and presenting the results in a suitable format. The GIS has the ability to capture, store, manipulate, analyse and visualize the diverse sets of geo-referenced data [12,13]. The hydraulic model, on the other hand, which is based on the physical representation of the natural phenomena, has the ability to simulate the dynamic behaviour of flow in the channel, which can be used as input for GIS to generate flood maps.

In the Kingdom of Morocco, the most frequent natural hazard occurring event is due to flood. Table 1 summarizes the natural disasters that occurred in Morocco between 1995 and 2005 [14]. The table indicates that floods have been the most frequently encountered natural disasters in the country [15]. The number of affected people and lives lost due to floods exceeds any other natural disasters in the past twenty years [16]. In Morocco, there is a need to conduct studies on the flooding potential in the cities located especially in oasis areas, which are most vulnerables than others situated far from the rivers. The aim of this study is to develop a flood simulation model for the area surrounding the Tata city (Tiguezmert region), situated on the SE part of Morocco. The physic parameters of the Tata basin provide an ideal environment to high floods: the basin is compact, with steep slopes, soils with little to medium permeability, with a dense drainage network and rather clear plant cover. This morphological situation contributes to amplify peak discharges recorded downstream of the basin.

The approach will consist on a simulation of extreme discharges along the valley and the flood specialization in relation with different discharges frequency (Figure 1).

***Corresponding author:** Said Boutaleb, Laboratory of Applied GeKeuology and Geo-Environment (LAGAGE), Ibn-Zohr University AGADIR, Morocco, Tel: 00212661198817; Fax: 00212528236976; E-mail: saidboutaleb1@yahoo.fr

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Killed People			Economic Damages		
Disaster	**Date**	**Killed**	**Disaster**	**Date**	**Cost (US$ X 1000)**
Flood	1995	730	Drought	1999	9,00,000
Earthquake	2004	628	Earthquake	2004	4,00,000
Flood	2002	80	Flood	2002	2,00,000
Flood	1997	60	Flood	1996	55,000
Flood	1995	43	Flood	1995	9,000
Flood	2003	35	Flood	2001	2,200
Flood	2010	32	Extreme temp.	2000	809
Mass mov.dry	1988	31	Storm	2005	50
Flood	2008	30			
Flood	1996	25			

Table 1: Human and economic losses from disasters occurred between 1980-2010, in Morocco (A. Karmaoui and al. 2014).

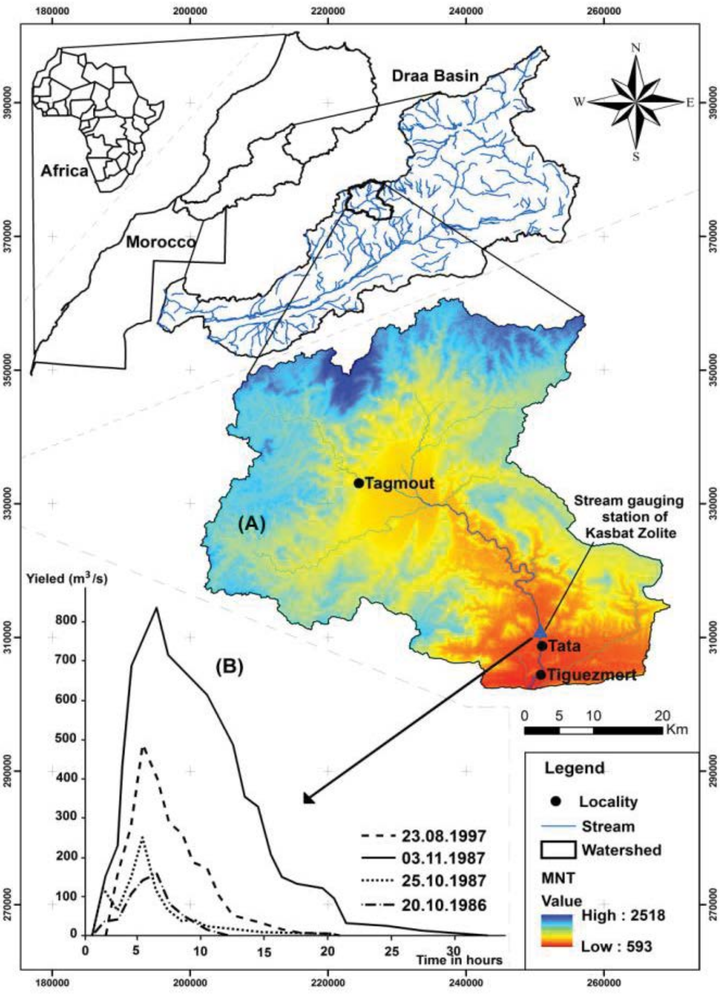

Figure 1: Geographic situation of Tata basin: (A) Digital Elevation Model (DEM), B) Discharge hydrograms of Tata.

Materials and Methods

Study area

Oued Tata's basin is a well-individualized hydro graphic system of the Anti-Atlas mountain chain. It's located within the province of Tata, which it's situated in the southeast of Morocco between Lambert coordinates X (200,000 and 280,000) and Y (290,000 and 360,000) (Figure 1A). The main stream of the basin has its sources at the high elevations of the Anti-Atlas Mountain, around 2000 masl.

The climate of the basin is continental and semi-arid, with low rainfall (<150 mm/year) and high average summer temperatures (>32°C). The range of daily and seasonal temperatures is also high (19°C in winter and 30°C in summer). The wet period is between October and March, and the dry period can extend from April to September. About 18 tributaries from the mountain ranges on either side of the valley contribute significantly to the flow of the Oued Tata. The contribution from springs is very low (<1 m^3/s). The monthly discharge of Oued Tata is highly variable, because of the large variability in rainfall in the basin.

The mean yearly discharge is about 3.2 m^3/s. The catchment basin of Tata river is compact, with a Gravelius Index of 1.84 and characterized by a dense drainage network (Figure 2a).

The both slopes of the basin are steeps: 10 to 30 degrees in general, but may be as high as a maximum of 50 to 60 degrees in some areas of the basin which makes this river as one of the major watercourses that erode the southern slope of the Anti-Atlas Mountains (Figure 2b). Its erosional effectiveness enhanced by the medium size of the watershed (2378 km²) and the magnitude of its flood flows (as great as 800 m^3/s).

From a geological point of view, the valley is mainly entrenched in Georgian limestone's and Adoudounian conglomerates in the centre of the basin, bordered on the north by Precambrian conglomerate's and granitic formation's, and on the south by Precambrian shists. Above these materials are quaternary alluvium deposits, as shown on the generalized geologic map of Figure 2c. The lithology of the main strata in the basin, which is dominate by little and medium permeable formations, enhance streaming and flood risks (Figure 2d).

The rainfall peak takes place generally in the valley from March to November, while the hydrologic peak, more individualised, has been recorded to occur only in August. The basic data of the hydrological model consist on the maximum annual discharges measured at the

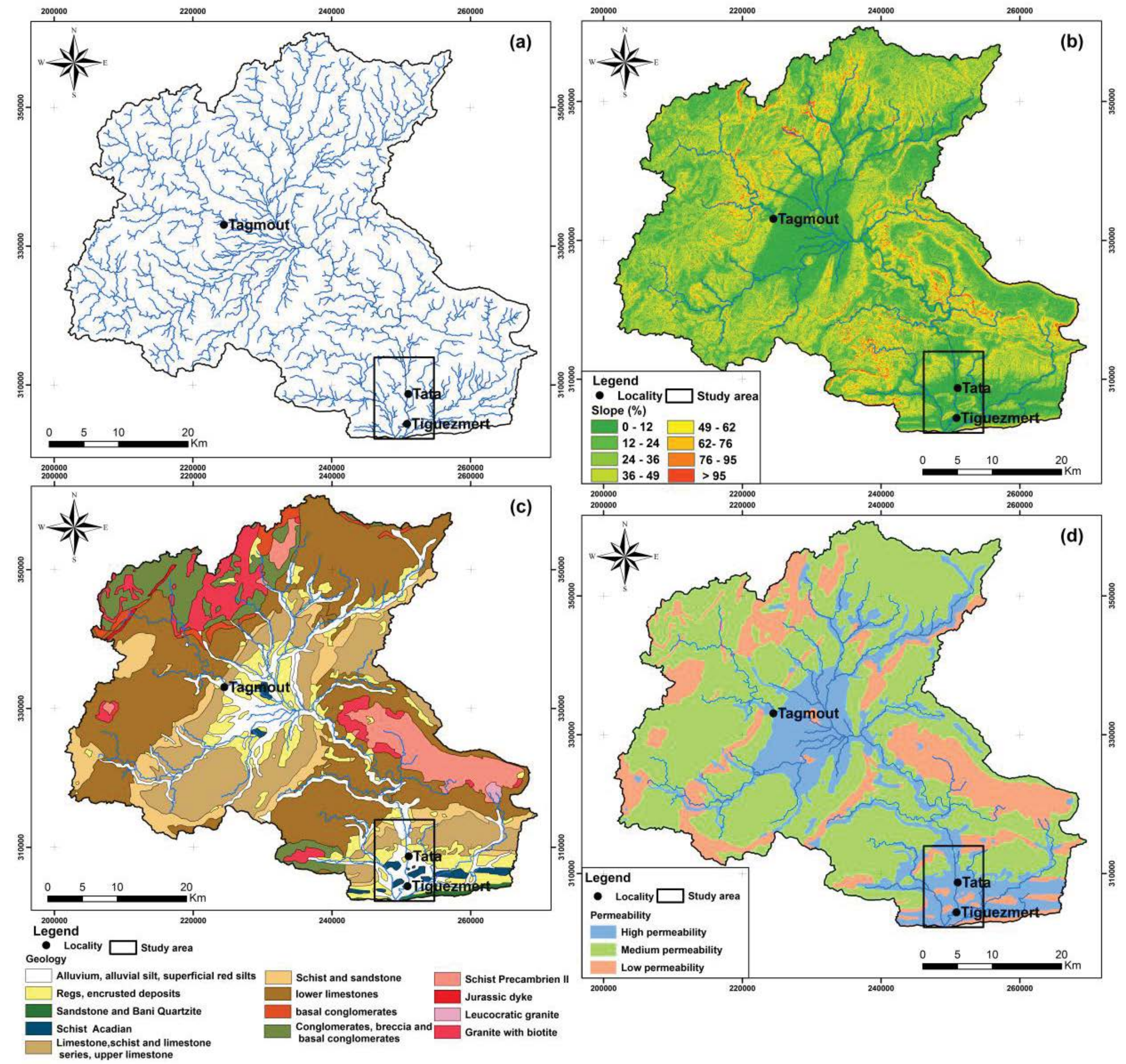

Figure 2: Physical characteristics of the study area: (a) Drainage network map of Tata basin, (b) Slope map of Tata basin, (c) Geological map of Tata basin and (d) Permeability map on the basin.

level of the hydrometric station of Kasbat Zolit (Table 2). These data cover a 26-year period, from 1985-1986 to 2010-2011. They come from both isolated stream gauges and limnnigraph recordings and have been provided by the Sous Massa Hydraulic Basin Agency.

Hydraulic and floodplain modelling

Hydraulic modelling is used to evaluate important elements of free surface fluid flow such as for flood forecasting and producing inundation maps [17]. The models are applied to the floodplain area that is usually inundated by the floods. HEC-RAS is a windows-based hydraulic model developed by the U.S. Army Corps of Engineers Hydrologic Engineering Centre [18] designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. In this study, HEC-RAS is used for steady flow water surface profiles, using the energy equation with an iterative procedure called by a standard step method [19]. The energy equation is written as follows:

Where:

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \qquad (1)$$

Z1, Z2 are the elevations of the main channel inverts,

Y1, Y2 are the depths of water at cross sections,

V1, V2 are the average velocities (total discharges/ total flow area),

α1, α2 are the velocity weighting coefficients that account for non-uniformity of the velocity distribution over the cross section,

g: Gravitational acceleration, and

he: The energy head loss.

A steady flow is a condition in which depth and velocity at a given channel location do not change with time. Therefore, gradually varied flow is characterized by minor changes in water depth and velocity from one cross-section to another.

The cross section sub-division for the water conveyance is calculated within each reach using the following equations:

$$Q = KS_f^{1/2} \text{ ,} While\, K = \frac{1.486}{n} AR^{2/3} \qquad (2)$$

Where:

K: Conveyance for subdivision,

n: Manning roughness coefficient,

Year	Q max [m³/s]	Year	Q max [m³/s]
1985-1986	44.9	1998-1999	130
1986-1987	133	1999-2000	101
1987-1988	833	2000-2001	0
1988-1989	775	2001-2002	831
1989-1990	0	2002-2003	244
1990-1991	0	2003-2004	206
1991-1992	0	2004-2005	419
1992-1993	0	2005-2006	80.4
1993-1994	93.3	2006-2007	162
1994-1995	243	2007-2008	0
1995-1996	6.62	2008-2009	590
1996-1997	490	2009-2010	673
1997-1998	217	2010-2011	80.4

Table 2: Annual maximum instantaneous discharge rates at Oued Tata.

A: Flow area subdivision,

R: Hydraulic radius for subdivision (wetted area/wetted perimeter)

S_f: Friction slope.

Otherwise, WMS software is a comprehensive environment for hydrologic analysis. WMS 8.1 can perform operations such as automated basin delineation, geometric parameter calculations, GIS overlay computations, cross-section extraction from terrain data, floodplain delineation, mapping, and storm drain analysis. Flood inundation modeling was conducted using one of the tools within WMS, the WMS River tool to construct an HEC-RAS flow model. HEC-RAS also performs a step backwater curve analysis for either steady state or transient conditions to determine water surface elevations and velocities.

Methods for flood inundation mapping

There were three basic steps to obtain the flood inundation map of Tata region:

1. Preparing a triangular irregular network (TIN) which represents the topography for the study area. The TIN is a type of DEM (digital elevation model) created from digital contour data sourced from the GDEM-ASTER website. The contour data have a vertical accuracy of 1 m. In this study, TIN data were generated based on the DEM with a 30 × 30 m spatial resolution, after resampling from the digital contour of 1 m. This is to optimize time on the delineation process. This TIN resolution is suitable to be applied for a floodplain area to assess flood hazards [20].

2. Preparing water surface elevation data as read in as a scatter point data set with stream stage values which are derived from HEC-RAS and subsequently read into WMS. Water elevation data consist of a series of surface water elevation points defined as x, y, z (where z is the elevation of the water surface). Some parameters required for the hydraulics model in HEC-RAS are stream centerline, main channel banks, cross-section lines, and material zones which are called channel geometry. The geometric data were derived based on the exisiting satellite imagery from Google Earth. A total of 51 cross sections were taken over the single reach modeled as seen in Figure 3a. The great number of cross-sections was chosen for more details of flood maps. Reducing the number of cross-sections result in poorer inundation maps [21]. An example of the water surface elevation is given in cross section of Figure 3b. Roughness coefficients (Manning's n) used in the study area were 0.03 for river area, 0.10 for Agriculture area, 0.08 for urbanized area and 0.04 for bare soil.

3. Mapping of flood inundation areas: After computing water surface elevation along the channel geometry of the Tata oued, mapping of flood inundation areas was carried out using the flood analysis function of the WMS package. It involves interpolation of water surface elevation on the cross-sectional area along a 800 m radius (Figure 3c). The flood depth information for each location within the inundated areas has been identified by clicking at the expected location on the flooded areas. The methodology using the coupled WMS and HEC-RAS is illustrated in Figure 4. Six methods of frequency distribution widely used in metrological analysis have been used to represent the maximum annual series of flood discharges. To choose between distributions, the visual fitting comparison, although necessary, is highly subjective and misleading. To overcome this subjectivity, several methods are available for the choice between distributions. One can use the moment ratio diagrams whether the ordinary or the linear

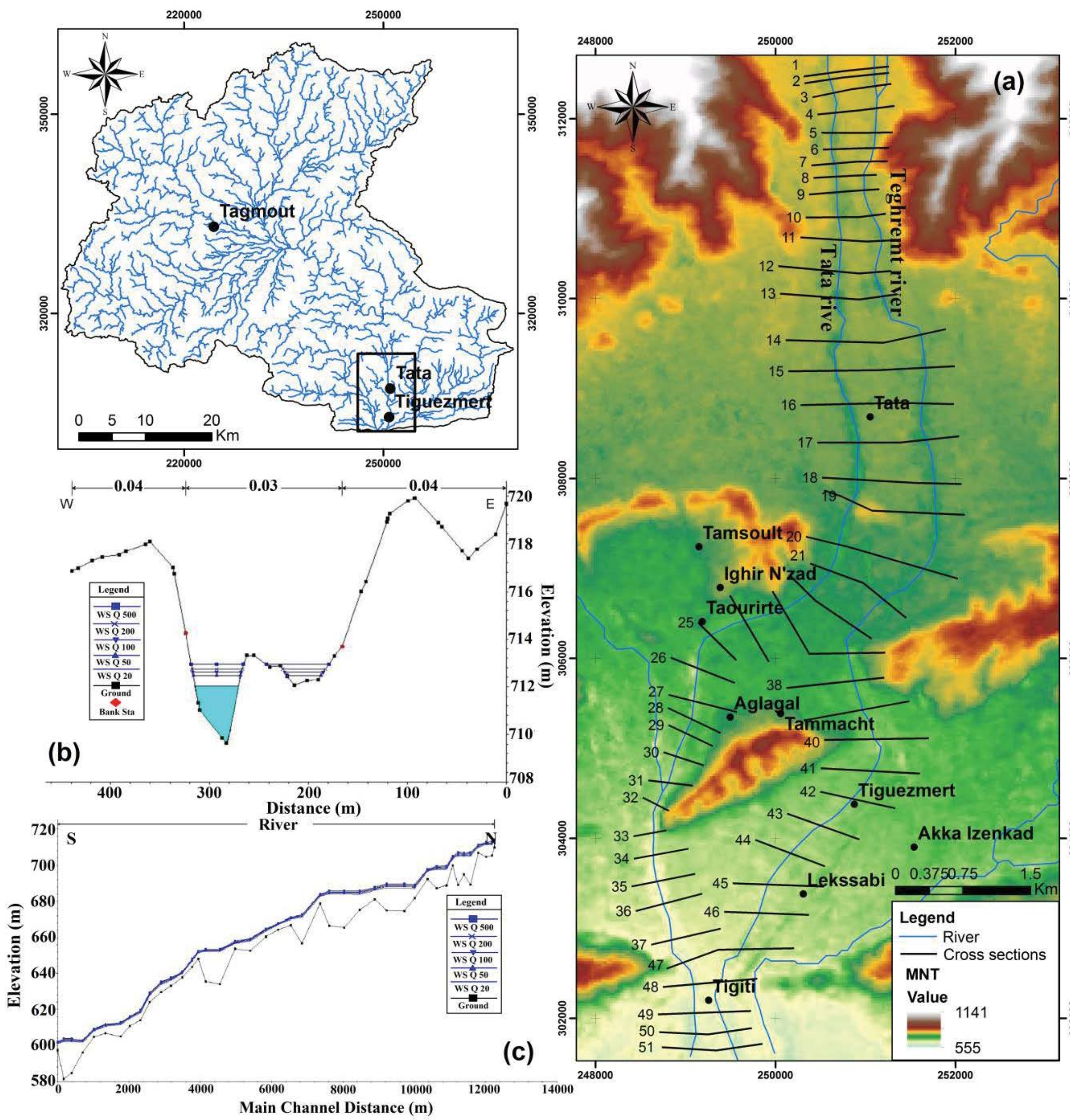

Figure 3: (a) Cross-section lines used for modeling with DEM as a background image, (b) Water surface elevations at the outlet for different return periods, (c) Water surface profile along the main channel (Tata river) for different return periods.

moments. Another methodology is the one proposed by El-Adlouni et al [22]. To choose between tested distributions, the Akaike Information Criterion (AIC) [23] and Bayesian Information Criterion (BIC) [24] can be used. Both criteria are based on the deviation between the fitted distribution and the empirical probability with a penalization that is function of the number of parameters of the distribution and the sample size. The distribution having the smallest BIC and AIC is the one that best fits the data. These criteria are defined as:

$$AIC=-2*\log Lik + 2*k$$

$$BIC=-2*\log Lik + K*\log (N)$$

Where,

Log *Lik* represents the log-verosimilitude of parameters associated to data,

K stands for the number of independent parameters within the model,

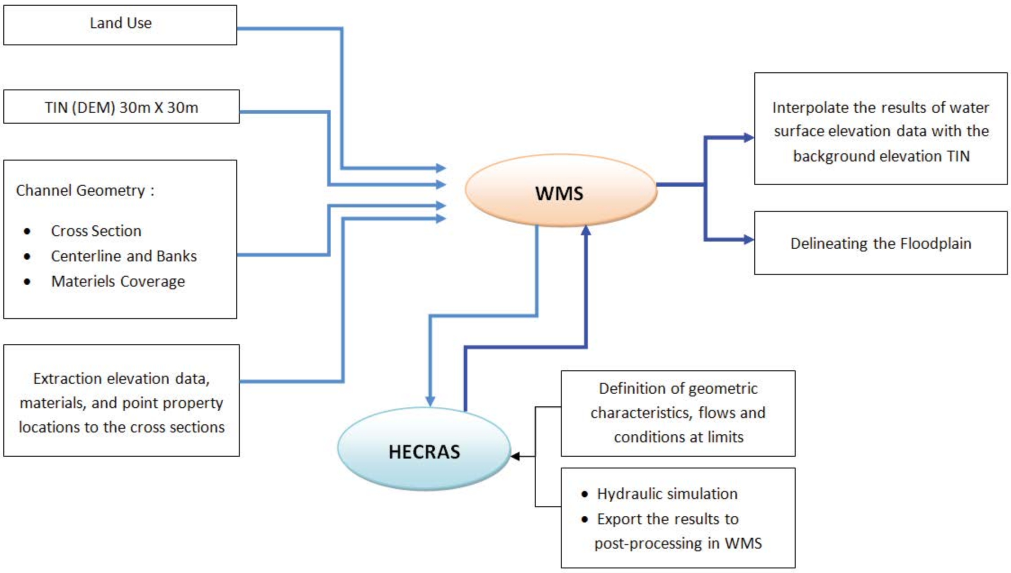

Figure 4: Schematic diagram of flood model applied for Tata basin.

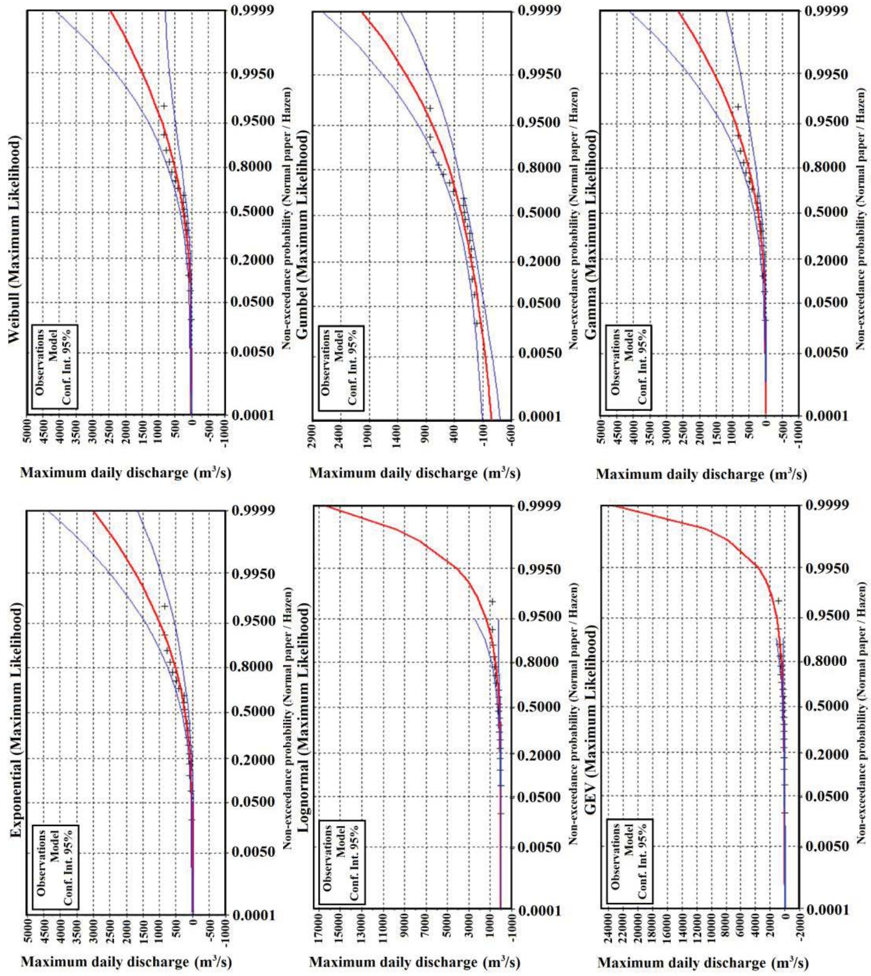

Figure 5: Results of the adjustment of different statistic laws to flash floods of Tata Oued at Kasbat zolite gaujing station (upstream of Tata city).

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N is the number of individuals composing the sample.

Results and Discussion

Inundation map

Flood return periods are normally estimated from a flood frequency analysis performed on observed data. The Weibull distribution has shown to be the strongest fitting distribution as shown in the Figure 5. The results of comparative analysis of adjustments of statistical laws are summarised in Table 3. The distribution having the smallest BIC and AIC is the weibull distribution which confirm the graphical analysis. The determination of peak discharges for different retour periods was done by the application of Weibull distribution. Considering that, the mainstream (Tata river) splits in two rivers: Tata and Teghremt, just downstream from the Tata city, and taking the hypothesis that this flow is divided into two in extreme events, the peak discharges used for the modelling of flooded surfaces for each river and for each return periods are showed in Table 4.

Basing on these peak discharges, the floodplain delineation process was executed for the five scenarios (20, 50, 100, 200 and 500 years). The floodplain delineation was automatically simulated in WMS by interpolation along a 800 m radius of the cross-sectional areas. This radius was obtained after sensitivity analysis of the model results. The minimum flood depth for all scenarios was almost zero (m), the maximum flood depth is 6.90 m, while the average flood depth ranged from 0.50 to 3.10 m. Most of the areas, situated in the eastern part of the steady area (Tiguezmert and Leksabi flood plain), are affected by Teghmert river flood and a small portion in the western part (Aglagal and Tigit areas) are affected from the Tata river.

The inundation depth is large in depth up to 3.50 m and within this depth of flood, the effect on life and property is very high. Thus depending on this understanding, it is recommended that the area is to be free of any agricultural activities and residence of people in order to avoid the risk of flooding in these areas, especially in the Tiguezmert and Leksabi areas which are affected mainly from the flood and should be avoided from any infrastructure development and investment. According to the result of this flood inundation mapping, the area could be free from any of activities.

The difference in lateral extension of the flood inundation between the Tata and the Teghmert rivers is due to the topography of the flood plain between the two regions as it is showed in Figure 6.

The effect of topography on a flood inundation map varies depending on the size of the river, and modeling approach [21]. As we can see on the cross sections in the upstream part of Tata city, the two rivers seems to have the same encaised value (Depth of the oued: 20 m for profile 1 and 14 m for profile 2), however in the dowtream part of Tata city, Tata river is narrow and more deeper (can reach more than 35 m) than the Teghmert river wich seems less encaised (<18 m), as represented in Figures 7 and 8. A decrease of deep river in Tata oued reduces the inundation width in the map.

Hazards map

To develop the flood hazard map, the peak flows for the two rivers, situated upstream of the Tata city, simulated by HECHMS, were inputted into HEC-RAS and the solution generated by HEC-RAS model was imported and read by WMS. The process was repeated for all return periods. Each time, a new scatter point file containing the water depths resulting from the HEC-RAS simulation was read into WMS as two-dimensional scatter points that are connected to delineate the flood inundation. These scatter points, which contain the water surface elevations, were interpolated at 300 m spacing along the main channel centreline where cross sections were extracted in the building area to achieve more accurate floodplain delineation. The inundated areas were represented as flood polygons with various colors in the developed flood hazard map, as shown in Figure 9, for the 500-year design storm. Both Tiguezmert and Leksabi villages has developed a flood risk map indicating the areas divisions that are subject to frequent flooding. A comparison between the 20 and 500-year flood inundation zones shows a very significant lateral extension for the 500-year flood which can seriously affect residences and agricultural areas. Based on this, the flood of 500 years was adopted for the mapping of flood risks in this region. The map, which is based on observations, includes three categories: high, medium and low hazard. This map reveals that a relevant part of the farming areas (65%) of the Tiguezmert region is exposed to flooding hazards, and that more than 50% of houses of the Leksabi village faces the same risk. In fact, the latter corresponds to an urban area, where water infiltration rate is greatly reduced. It is hence necessary to plan protection measures upstream this village to ensure the protection of people and goods. The inundated area intersects with several major and minor roads in the two villages, indicating the risk of driving through these roads during flood-events.

Model	XT	P(Mi)	P(Mi/x)	BIC	AIC
Weibull (Maximum Likelihood)	1310.855	7.69	21.43	276.12	274.128
Gamma (Maximum Likelihood)	1362.29	7.69	20.85	276.175	274.183
Exponential (Maximum Likelihood)	1497.892	7.69	10.04	277.636	275.645
Lognormal (Maximum Likelihood)	3098.347	7.69	3.98	279.488	277.496
GEV (Maximum Likelihood)	2527.452	7.69	1.43	281.532	278.544
Gumbel (Maximum Likelihood)	1109.743	7.69	1.14	281.979	279.988

Table 3: Results of the application of AIC and BIC criteria to estimation of flash floods of Oued Tata. P (Mi): A priori probability; P (Mi/x): A posteriori probability (Method of Schwarz); AIC: (Akaike Information Criterion); BIC: (Bayesian Information Criterion).

Return periods (years)	Predetermined discharges of Tata river in (m^3/s). Upstream of Tata City (Kasbate Zolite jauge station)	Predetermined discharges (m^3/s) for Tata and Tighremt rivers (dowsteram of Tata city)
500	1720	860
200	1490	745
100	1310	655
50	1130	565
20	889	444.5

Table 4: Peak discharges for different return periods of the Tata and Teghmert rivers.

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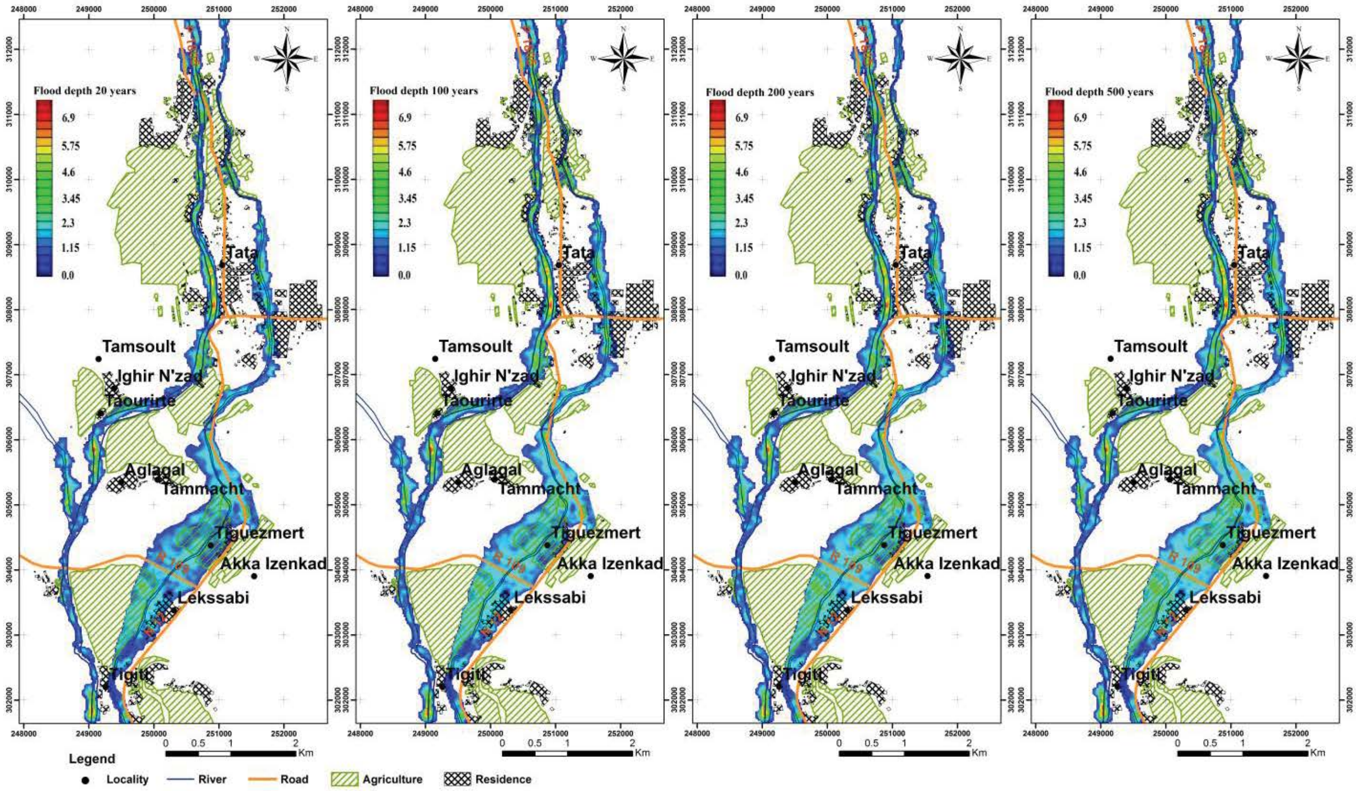

Figure 6: Flood map limits of both Teghremt and Tata rivers for different return periods.

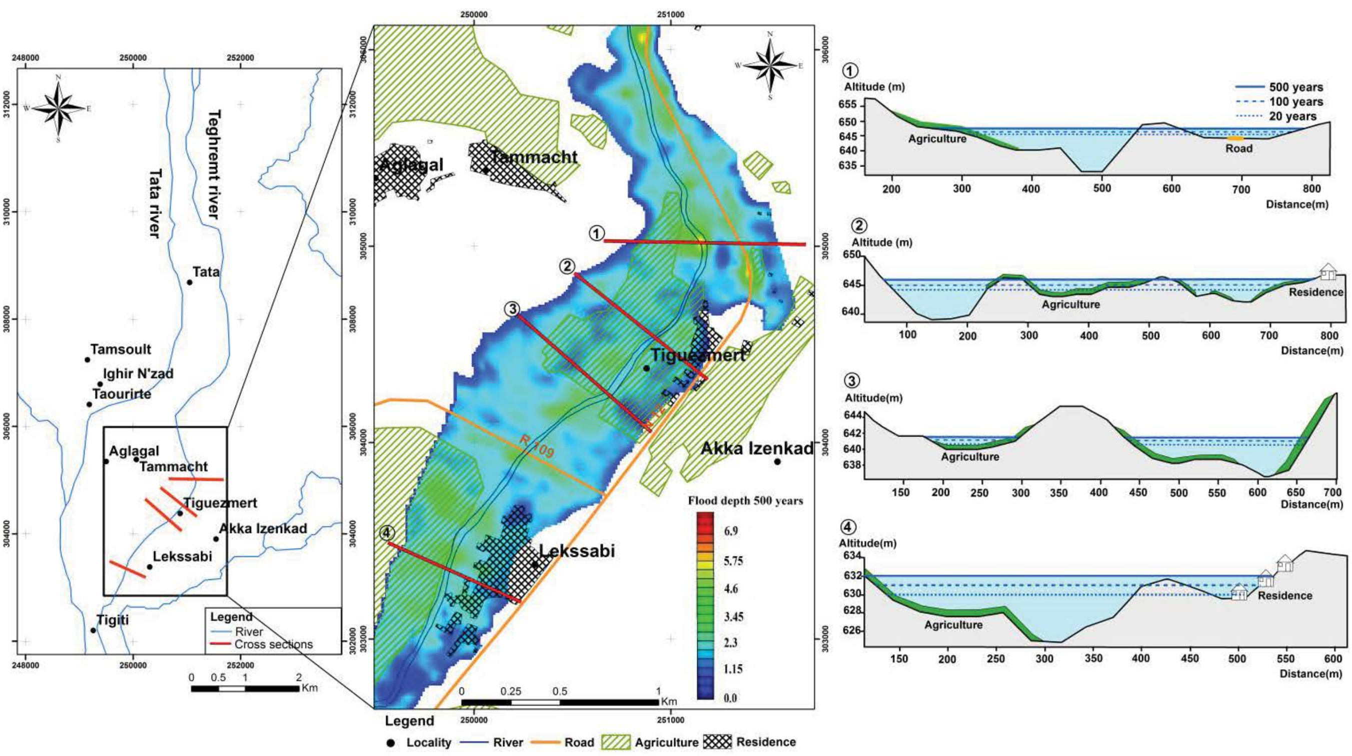

Figure 7: Water surface elevations of flood at different cross sections.

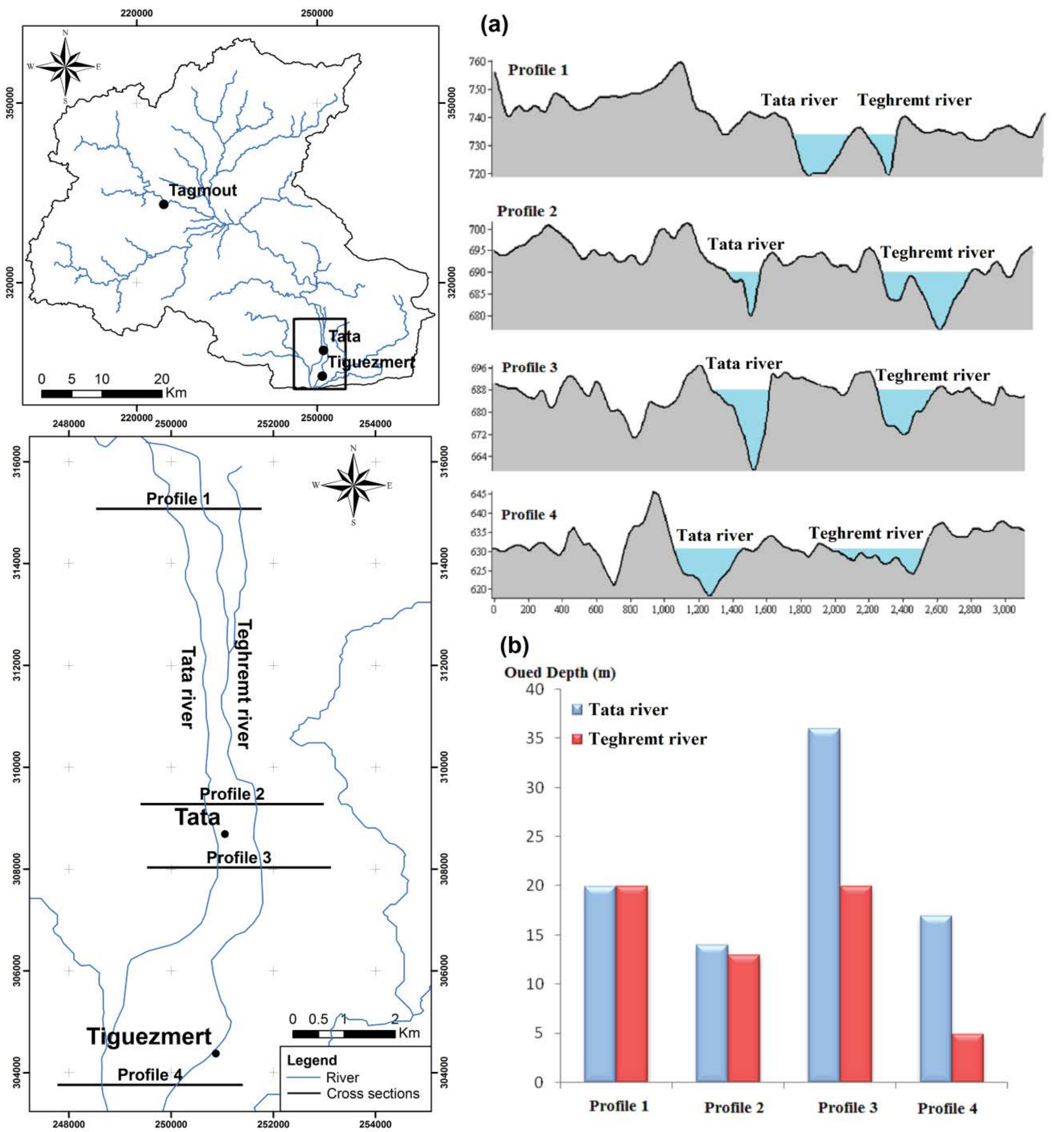

Figure 8: (a) Topographic profiles at four cross sections (upstream and downstream of the Tata city), (b) Deep of Tata and Teghmert rivers according to different profiles.

The estimation of the population liable to be affected by floods is made by crossing the limits of the 500-year return deluge with the map of population density per village, at around 40%. This percentage is rather low in relation with the flooded areas in case of the generalisation of a habitat without multi stored buildings.

Conclusion

The simulation and spatialisation (mapping) of flooding hazard in the valley of Oued Tata using an on-purpose computer model has permitted to reveal the presence of two black points with a high flooding risk which would affect the road infrastructure, as well as

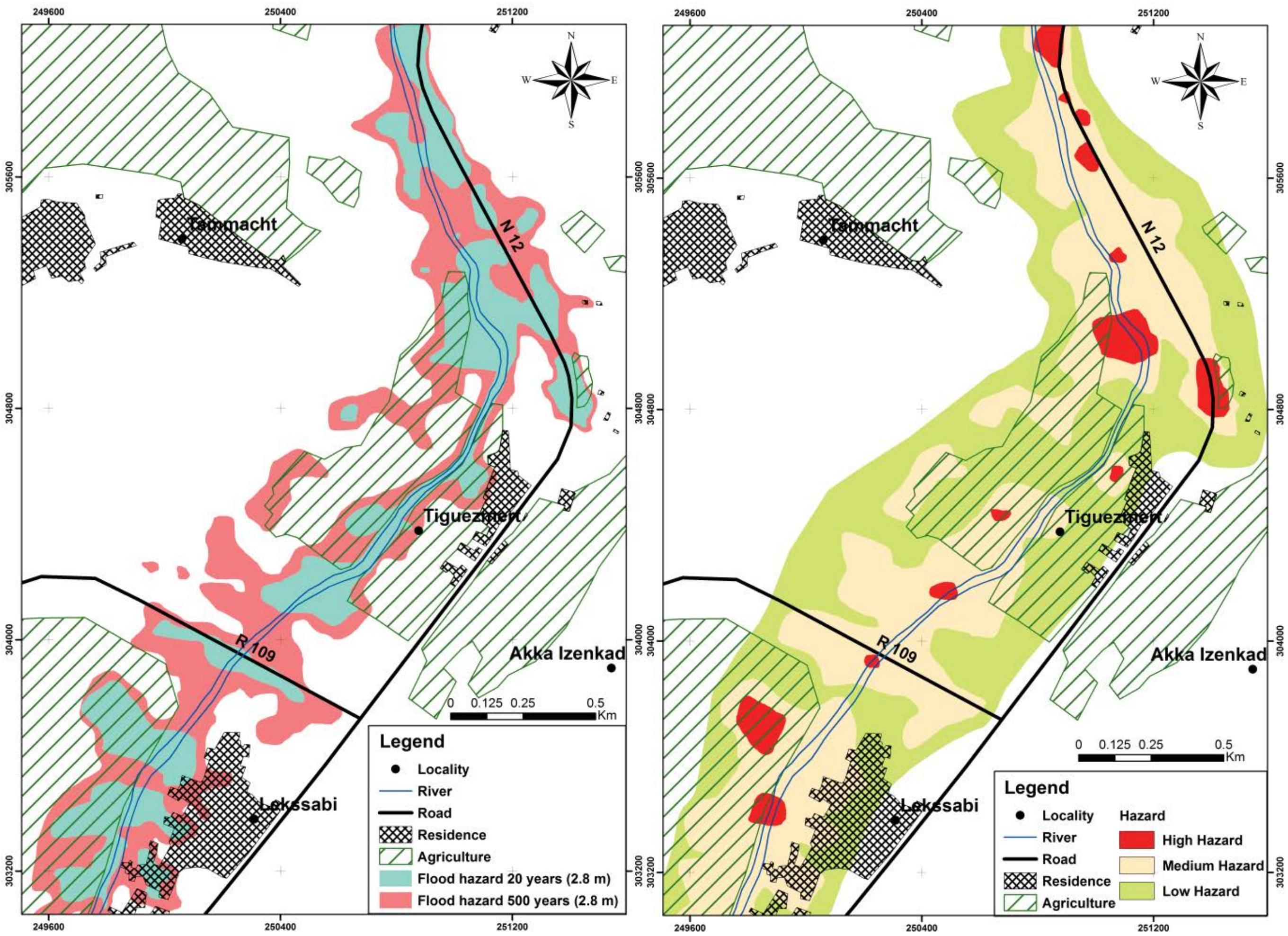

Figure 9: (a) Comparison between the 20 and 500-year flood Hazard Maps in Tiguezmert region, (b) Intensity of flooding hazard in the Tiguezmert region.

farming activities and buildings of resident population. In this sense, for the 20-year return flash flood, estimated in 889 m^3/s, the extension of the wetted surface on the stream cross section profile has reached the first houses and cultivated fields on the main river bed. The 500-year flash flood has obviously been much more extense. Its peak discharge of 1720 m^3/s, generated within a catchment area of only 2300 km^2 gives evidence of its power and gravity. The simulation of its lateral extension calls special atention mainly because it covers the only road communicating the valley and because of the flooding of great surfaces with human activity, mainly trade, farming or residence. These results have been obtained from rather reliable hydrometric measurements and a numeric topograhic model with a 30 m resolution. A finer resolution would have provided more accurate results, with the possibility of extrapolating the simulation further downstream. Additionally, attention is to be drawn on the human and economic costs of damage from flash floods, with the necessity to ellaborate land occupation plans preserving citizen's goods and their own safety. A firm and enforcing legislation dealing with preservation of the hydraulic public domain is required for minimising the recurrent damage of the oued's overflow.

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