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CASO PRÁCTICO

Cartography of flood hazard by overflowing rivers using hydraulic modeling and geographic information system: *Oued El Harrach* case (North of Algeria)

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Abstract: The aim of the present study is the management of flood risk through the use of cartography of flood hazards by overflowing rivers. This cartography is developed using modern simulation tools namely the hydraulic model (HEC-RAS) as well as the Geographic Information System (ArcGis). The study concerns *Oued El Harrach* (North of Algeria) surrounding area which has been subject to several floods causing significant human and material damage. This loss is a consequence of the use flood zones as habitats for people. This can be avoided in the future by use the mapping of the spatial extent of the flood hazard on the land of the *Oued El Harrach*. Hence the importance of the cartography developed in this study as an essential tool for decision makers in prevention, protection and management of flood risks.

Key words: inundation, hydraulic modeling, cartography, GIS, high-resolution images, Algeria.

Cartografía de riesgo de inundaciones por ríos caudalosos mediante modelos hidráulicos y SIG: caso de *Oued El Harrach* (Norte de Argelia)

Resumen: El objeto de este estudio es la gestión del riesgo de inundaciones mediante el uso de cartografía de riesgo de inundaciones por ríos caudalosos. La cartografía se obtiene mediante aplicaciones de simulación modernas, como el modelo hidráulico (HEC- RAS) y la aplicación informática de Sistemas de Información Geográfica (SIG) ArcGis. El estudio se aplica en los alrededores de *Oued El Harrach* (norte de Argelia), objeto de varias inundaciones que han generado pérdidas humanas y materiales considerables. Estas pérdidas son consecuencia del uso de zonas inundables como zonas residenciales, pudiendo evitarse en el futuro en la zona de *Oued El Harrach* con la ayuda de cartografía del alcance espacial de los riesgos de inundación. Por ello la importancia de la cartografía desarrollada en este estudio como herramienta esencial para los gestores en prevención y protección en materia de riesgos de inundaciones.

Palabras clave: inundación, modelos hidráulicos, cartografía, SIG, imágenes de alta resolución, Argelia.

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1. Introduction

Our societies have always been confronted with flooding, rivers represent a threat and a wealth for residents. Bravard and Petit (1997). The concerns about the rises in rivers levels, particularly rare ones, are many and date back to civilization origins. The estimate of rivers levels rises flows is essential, on the one hand for the management of water resource and on the other hand for the protection of both populations and properties against floods, i.e. identification of flood risk and setting up of appropriate structural and non-structural measures (Hingray *et al.*, 2009).

Algeria is one of the countries vulnerable to flooding risks linked to climatic hazards. The floods caused by the rising of different rivers (Oued) levels of Algeria are catastrophic as far as human and property damages are concerned, as reported in the *Schéma National d'Aménagement du Territoire* (SNAT 2025, 2004). These considerable damages are mainly due to urbanization and industrialization in flood plains that they consequently had a vulnerability increase of both, properties and persons. However, taking the risks of development and town planning schemes into account is very recent in Algeria. It is after the scale of the last devastating disasters such as floods of Bab El Oued in 2001, the earthquake of Boumerdes in 2003 and the Skikda gas plant explosion in 2004 that Algerian state has become aware of these extensive risks and the need to take them into consideration in the space management. After SNAT 2025 (2004), the Act no. "04-20" was promulgated related to taking the risks into account during the use of space, by determining and delimiting disaster-prone areas, flood risk in particular. The aim of this study is to present cartography of flood hazard in order to determine and delimit the flood risk areas. The methodology adopted is the use of Hydraulic Modeling as well as the Geographic Information System (GIS) to carry out this cartography and we propose some preventive recommendations.

2. Area of study

The study area of the present work concerns the principal river of the watershed of Oued El Harrach, that is to say linear transect of 18.2 km inside the administrative boundaries of the province of Algiers. It crosses the territory of twelve densely urbanized municipalities that are: Hussein Dey, Mohammadia, El Magharia, Bach Djerah, El Harrach, Bourouba, Saoula, Gué de Constantine, Baraki, Birtouta, Sidi Moussa and Ouled Chbel. This river represents a high land-use on these two riverbanks particularly in the flood plains (Figure 1).

2.1. The watershed of River Oued El Harrach

The watershed of Oued El Harrach is located in the north of Algeria and is part of the coastal watershed of Algiers, with elongated shape SW-NE, it is spread out over an area of about 1236 km^2, of which 600 km^2 are in Atlas Blideen, 100 km^2 in Sahel and 500 km^2 in Metidja plain within a 188 km radius (DRHEE, 2010). The main river of this watershed is Oued El Harrach that begins from Atlas Blideen and flows into the Mediterranean Sea. From an administrative standpoint, the watershed of Oued El Harrach extends over the territory of four provinces (Média, Blida, Algiers, and Boumerdes), the province of Algiers is the most affected by the floods of Oued El Harrach, it is located downstream of Metidja plain with a high urbanization density concentrated in the lowlands (Figure 2).

Topographically, the watershed of Oued El Harrach is divided into three different areas, namely: the South area is mainly comprised of Atlas Blidéen massif and it represents the biggest area covered with this basin, it has an area of about 600 km^2. The Northwest area is made up of the slopes of Sahel's hills; it has an area of about 100 km^2 , and the third area (from Atlas Blideen until the sea) represents Metidja Plain and it covers an area of 500 km^2 (Figure 3).

The highest points of the watershed are: Kef Takhrina (1478 m), Harn Belek (1952 m) and Chrea (1526 m) in the Southwest of the watershed. The lowest point is situated at river mouth in the Mediterranean Sea.

2.2. Stream network of the watershed of Oued El Harrach

The watershed presents a very dense river network, drained by the principal collector

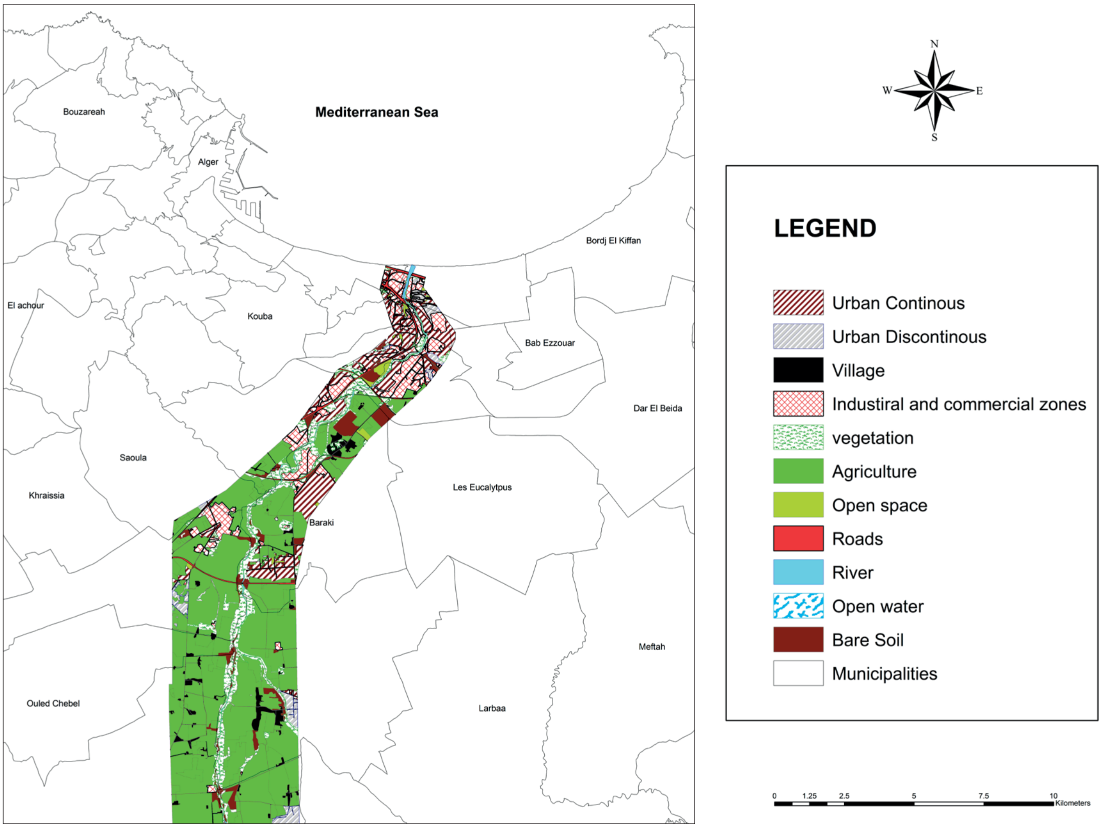

Figure 1. Geographic Situation and Land-use of River El Harrach.

"Oued El Harrach" that crosses Metidja plain and receive the waters of the main seven reaches (Figure 4). It has its source in the north area of Atlas Blidéen that is formed by the confluence of Akka river with Mektaa river, it flows in the direction of the Northeast into Metidja plain. During the crossing of this plain, it receives its largest reach Oued Djemaa coming from the South and having its source in Atlas also. Further to the North, on its left bank, it receives three other reaches; Oued Baba Ali, Oued Terro, Oued Kerma and Oued Ouchaih. Finally, about 3 km of its mouth, it receives on its right bank the river Oued Smar coming from Metidja.

The river El Harrach has gone through different risings, some of which were catastrophic and have caused huge floods, human and property damages. These floods phenomena are not new, but they are quite frequent nowadays owing to the strong population, urban and economic growth in the neighboring cities of this river (Oued). The main events that Oued El Harrach has known and their damages are presented below (DRHEE, 2010).

- November 1846: river level rising of 2 m caused the death of 23 persons and the disappearance of 7 houses.
- 1906: river level rising of one meter causing many casualties, clearing works of banks were engaged and the river mouth was removed from sand.
- 1911; 1913; 1923; 1931; 1935; 1936; 1939; and 1946: floods causing many casualties.
- 1954: huge flooding (1000 m^3/s): flooded the area of El Harrach industrial and reached 1.60 m of height (16.88 m above river level NGA in Gue-de-Constantine). Drainage works of banks were undertaken, we raised the roads and the railway tracks and we created a sandpit at the mouth of river Oued El Harrach.
- 1960: a flooding that caused considerable damages, the road Algiers – Constantine was cut

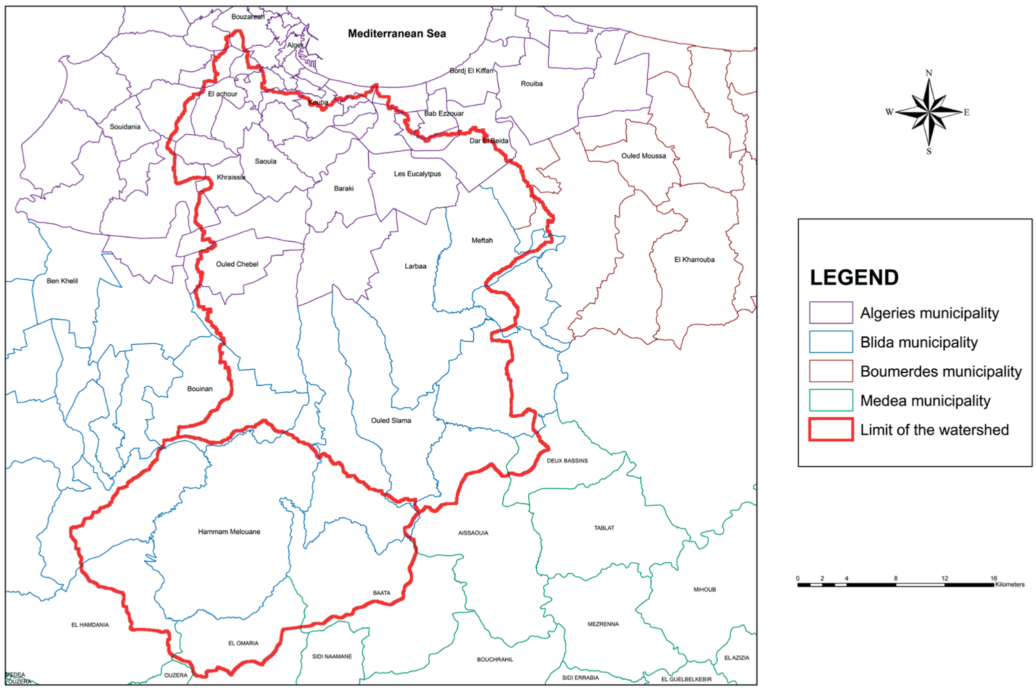

Figure 2. Administrative situation of the watershed of EL Harrach.

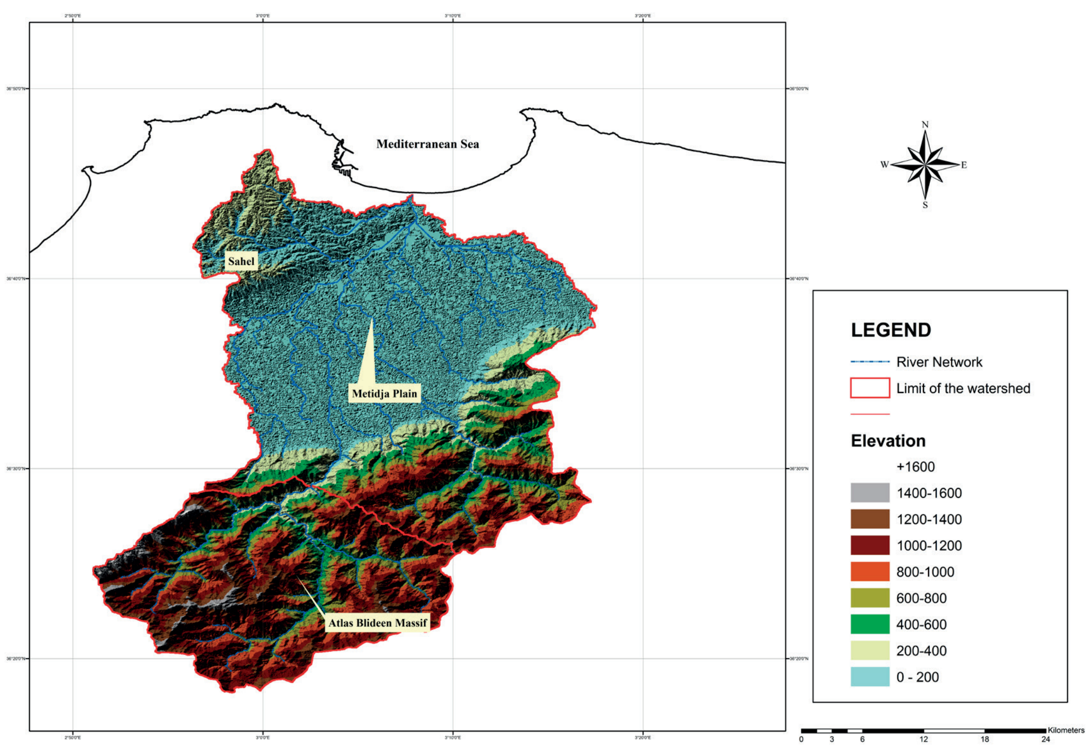

Figure 3. Topographic units of the watershed of El Harrach.

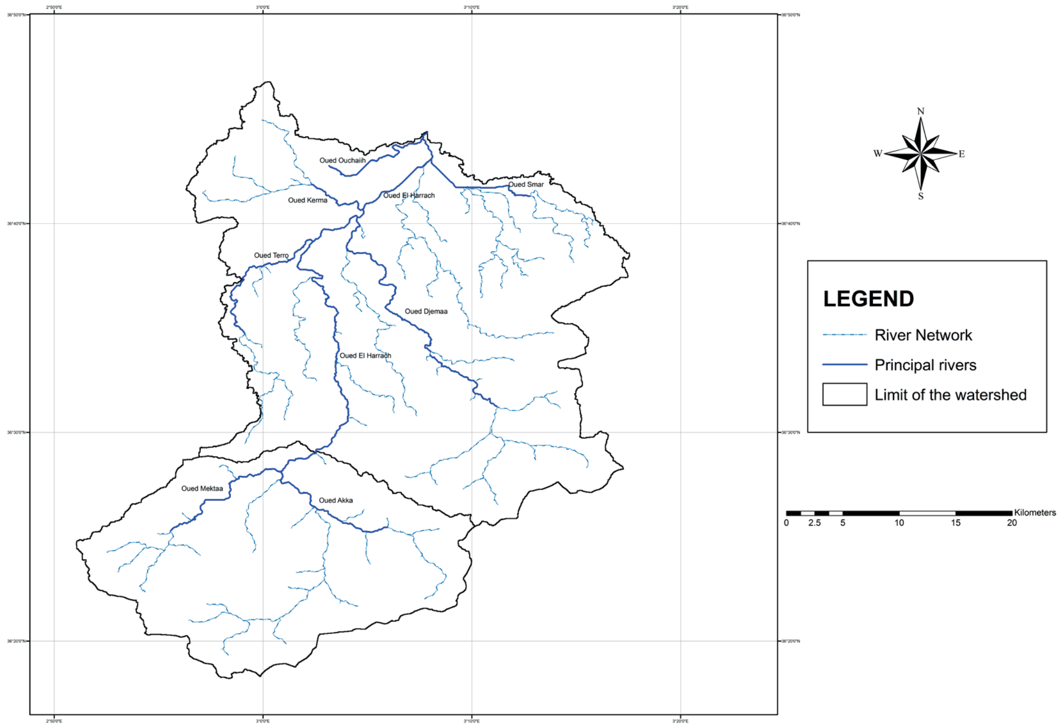

Figure 4. River network of the watershed of El Harrach.

off and the railway track was swept away at several places. Water reached one meter in some neighbourhoods of Gue-de-Constantine and the industrial zone of river Oued Smar was brought to a standstill for almost one month.

- 1970: 25-meters rise in river level (Oued Terro) NGA that flooded Baba Ali
- 1973-1974: the two industrial zones of El Harrach and Oued Smar were flooded.
- 1988: 41 affected families in the municipality of El Harrach.
- 1992-1994: a flood of 1500 m^3/s that inundated the industrial zones and residential neighbourhood.
- March 2007: a flood of 1650 m^3/s, which caused a flowback by wastewater pipelines towards the neighbourhood "Les trois Caves", the thing that made water level rise until one meter in some alleys and led to disbursement works. This flooding swept the branches of trees and solid waste away causing overflowing waters towards the basis camp Netcom and Boumati city.
- November 2007: stagnations of rainwater at several areas owing to the proliferation of illicit constructions on the banks of river El Harrach and the lands overthrusting resulting from building sites were signaled.
- October 2008: neighbourhoods totally inundated.

3. Materials and methods

The methodological approach adopted is focused on the hydraulic modeling and floods cartography on urban environment. The methodology followed consists in using the Geographic Information System (GIS) ArcGis and Hydraulic models HEC-GeoRAS & HEC-RAS to calculate the water depth of different peak flows of river El Harrach, and the mapping of this depth on urban space. The different steps taken in the preparation of this work are:

Georeferencing and data processing: this step is divided into two parts, the first is devoted to the georeferencing of cartographic data in the geographic coordinate system Northern Sahara 1959-UTM Zone 31N under GIS ArcGis, and the second is given over to processing and correction of study area Digital Elevation Model (DEM) under the GIS ArcHydro.

Extraction of the stream network and the physical characteristics of the watershed of Oued El Harrach starting from the study area DEM**:** Once the DEM is hydrologically corrected (depressions filling), we proceed to delimit the watershed of Oued El Harrach and extract the river network and the physical characteristics of the watershed (relief, slope, altitude, surface, perimeter) under the GIS ArcGis.

Extraction of geometric characteristics of Oued El Harrach starting from the DEM of the watershed of Oued El Harrach using geospatial hydraulic model HEC-GeoRAS under ArcGis: This step consists of the schematization of the section to be modeled by the HEC-GeoRAS tools and the extraction of river geometric characteristics.

Hydraulic modeling using the HEC-GeoRAS model**:** it consists in calculating water depths passing through the river. This step require two types of data, the river geometric data obtained by HEC-GeoRAS and the peak flows of different frequencies that have been obtained from the results of a study made by the Department of Hydraulic Resources and Economy (DHRE) of the province of Algiers on Oued El Harrach watershed, concerning rainfall-runoff modeling to assess the crossing hydraulic works capacities of river El Harrach.

Cartography of flood hazard by overflowing rivers under GIS ArcGis: This step is devoted to the export of hydraulic modeling results (water depths) to ArcGis for the representation of spatial extent of the risings of river El Harrach on urban environment. It allows defining flood hazard by overflowing river and delimiting vulnerable zones.

The data used to carry out this study are:

Mapping data**:** they include topographic maps, DEM raster, DEM vector, and two satellite images Quick Bird of high-resolution. The informations of each data is mentioned in Table 1.

Peak flows data**:** for different frequencies (10 years, 20 years, 50 years, 100 years and 200 years) obtained from rainfall-runoff modeling results made by the *Direction des Ressources Hydrauliques et de l'Economie de l'Eau* (DRHEE) of the province of Algiers in 2010.

Data processing has been done using the following tools:

Geographic Information System (GIS) ArcGis: used for gathering, extraction, querying, analysis, display, and the storage of data in a geodatabase. The GIS ArcGis capacity is used for data processing and data format.

Geospatial Hydraulic Extension HEC-GeoRAS (Tools for support of HEC-RAS using ArcGis): This extension is used under the Geographic Information System ArcGis, it was developed by "The Environmental Systems Research Institute" though a cooperative research and development agreement between the Hydrologic Engineering Centre (HEC) and ESRI. The extension is a set of tools used under ArcGis, it is specifically designed to process geospatial data for use with the hydraulic model HEC-RAS. The extension allows users to create geometric data from digital terrain model (DTM) and transfer them to the hydraulic model HEC-RAS. The DEM must be a continuous surface that includes the thalweg of the river channel and the floodplain to be modeled (Cameroun and Ackerman, 2009).

The Hydraulic Model HEC-RAS (Hydrologic Engineering Centers River Analysis System): this is a one-dimensional model integrated for hydraulic analysis; it allows simulating the flows in steady or unsteady regime, it was designed to manage rivers, harbours and hydraulic works. This system allows analyzing the flows in rivers beds, determining and carrying out the flood plains mapping. The model results can be applied to both floodplains management and flood studies. Input data of this model are the geometric data resulting from ArcGis and flows data coming from hydrologic modeling. The basic computational procedure of the software HEC-RAS for steady flows is based on the solution of one-dimensional energy conservation equation. Energy losses of water flows are evaluated by friction and contraction/expansion. The momentum equation is also used in situations where the water surface profile is rapidly varied. The equation solved by the software is based on Bernoulli's theorem; it is calculated from the momentum equation and represents the hydraulic head conservation (Brunner, 2010).

Table 1. Data used.

Data type	Map name / Description/ acquisition date	Scale/Resolution
Topographic map	ALGIERS NJ-IV- West	1/10000
Topographic map	ALGIERS NJ-31-EST	1/25000
Topographic map	ROUIBA NJ-31-IV-31 West	1/50000
Topographic map	ROUIBA NJ-31-IV-3-EST	1/50000
DEM (SRTM)	Of Algiers region	30 m resolution
Quick Bird Image 01	(Id=10100100094F1B00), 15/03/2009	THR (0.61m)
Quick Bird Image 02	(Id=101001000A87C200), 30/10/2009	THR (0.61m)
Land use	Urban district-roads-open space	
Administrative limites	Algiers wilaya and its municipalities	-

4. Results and discussion

4.1. Hydrologic Modeling rainfall-runoff

We have used in our study the results of hydrologic modeling rainfall-runoff of a study made on the watershed of Oued El Harrach by the group “Sogreah-Consultants-Sogreah Algeria” under the leadership of the Department of Hydraulic Resources and Water Economy, in the province of Algiers in 2010. Next, we present the model, the data used and the obtained results.

4.1.1. Hydrologic model Rainfall-runoff

The tool used for rainfall-runoff modeling needs on watershed of Oued El Harrach is the software PLUTON, developed by SOGREAH. PLUTON is a software of transformation rainfall-runoff, allowing calculation within unsteady regime of formation and propagation of flood hydrographs on many overlapping watersheds. Setting parameters of the model are:

- Time of rise in the water level (allows adjusting the hydrograph shape)
- Runoff coefficient (allows adjusting peak flows of elementary basins)
- Strickler-Manning’s coefficient of transfer sections between watersheds (allows adjusting peak flows at the confluences of river)

This model schematizes the complete watershed of Oued El Harrach, from the upstream mountainous part to the sea mouth, as well as the reaches watersheds (Djemaa, Kerma, Smar). The peak flows and the times at which peak floods occur have been modeled on each watershed of the studied area. For every considered frequency, the simulation model has been calibrated so as to reproduce hydrographs that correspond to both Baraki’s station and river mouth. This calibration allows obtaining a once-a-century flood on the downstream from Oued El Harrach, the subject of this study, for every considered frequency the setting has been done by modeling the rainfall of the same frequency on the whole watersheds, using runoff coefficient values determined after the analysis of geological maps (soil infiltration capacity) and topographic ones (land use) (DRHEE, 2010).

4.1.2. Data used for rainfall-runoff modeling

SOGREAH has an annual rainfall database, corrected and validated. Daily data have also been collected as well as hourly data (or every half an hour) on the major floods. The main data used are the annual maximal daily rainfalls, and annual rainfalls. For the study of relationships rainfall-flood, the period used is from 1970 up to 2007. Let’s remind that the work is done on both rainfall and hydrometric data over hydrological years: i.e, the years starting from 1st September of the year N up to 31st august of the year N+1. Concerning floods study, two hydrometric stations are particularly interesting: the station of Rocher des Pigeons located in the upstream of Oued El Harrach and the station of Baraki situated in the downstream of it, presented bellow (DRHEE, 2010).

Rocher des Pigeons Station (021301): Rocher des Pigeons Station is situated in the downstream from Hammam Melouane city, where the river Oued El Harrach represents a breakthrough in this station. Currently, the station in operation is located 1 km upstream from the old station location, at a marked bend that seems unstable.

Baraki’s station (021418): the station of Baraki is located on the river Oued El Harrach, under the

Table 2. summary of data received from gauging stations (DHRE;2010).

			Flood flow depth		Available data period	
Station code	Station description	Surface (km^2)	Starting year	Ending year	Starting year	Ending year
021301	Rocher des pigeons	390	26/09/1981	17/06/2004	1985	2004
021418	Baraki	970	19/10/1978	10/05/2003	1979	2002

bridge of the road between Baraki and Gué-de-constantine. It is built on a concrete slab of about 25 m long. Level measurements are taken using six scales situated at the right bank upstream from the bridge and recording device at the left bank (a cabin inside a factory). (Table 2).

Rains definition: for every frequency (return period), the rains modeled on the watershed, have been defined from Montana coefficients of Clairbois 2 ANRH station that possesses data over the longest period (DRHEE, 2010).

Calculation of concentration rate: The formula chosen for calculating the times of concentration of watersheds is a SOGREAH formula, appropriate to natural watersheds. It allows to free from the parameter "runoff coefficient". This formula was applied to all watersheds, except for the one upstream from the station of Rocher des Pigeons for which the Kirpich formula has been selected in order to better translate steep slopes on this part of watershed. The main characteristics of the defined watersheds in the model Rainfall-runoff are gathered in the following table (DRHEE, 2010).

4.1.3. Rainfall-runoff modeling results

The main results of hydrological modeling computation, obtained on the principal river of Oued El Harrach are shown in Table 3, that presents for every frequency (return period) the obtained discharge using rainfall-runoff PLUTON modeling. The results presented in this table regarding the main river, i.e. at hydrometric stations of Rocher des pigeons and Baraki, as well as the river mouth (DRHEE, 2010)

The hydrological modeling allowed knowing the peak flows for the different return periods (frequencies) (10 years, 20 years, 50 years, 100 years and 200 years). These flows will be injected into hydraulic model HEC-RAS for calculating water depth.

Table 3. Rainfall-runoff modeling results (DHRE;2010).

Return period (frequency)	Peak flow at Rocher des pigeons station (S=370 km^2)	Peak flow at Baraki station (S=970 km^2)	Peak flow at river mouth
T= 10 yr	480	980	1195
T= 20 yr	635	1285	1550
T= 50 yr	830	1695	2015
T= 100 yr	970	1980	2375
T= 200 yr	1100	2240	2720

4.2. Correction of DEM and Extraction of river networks

A correction of DEM has been made using Arc Hydro tools for identification of empty cells and the depressions filling, which has been compared with both a DEM vector and the topographic maps of study area in order to correct errors and complete the missing data. After DEM correction, a series of treatment has been set for extracting river network to define the watershed of Oued El Harrach and its river networks afterwards. This step allows obtaining a DTM on the scale of the watershed of Oued El Harrach. DEM allowed us to extract the basin's physical characteristics (surface, perimeter, slope, altitude, relief, etc.) and those of its river network (length, slope, upstream point, downstream point, etc.) all these data have been saved in GIS ArcGis.

4.3. Extraction of the geometric characteristics of the river El Harrach using the HEC-Geo RAS Model

The extraction of geometric data of Oued El Harrach is done in two steps; the first one consists of the schematization of the section to be modeled named (RIVER SYSTEM SCHEMATIC). This step is done using HEC-GeoRAS tools on the base of basin DTM and satellite images Quick Bird. It allowed us to schematize the main channel centre, flood plain, main axes of rivers and riverbanks by extracting terrain data from DEM. A difficulty has been found in the schematization of river (Oued) flood plain because it is completely urbanized. HEC-GeoRAS also allowed calculating the Manning coefficient of the section to be modeled by giving it the land-use extracted from satellite images. The second step consists of cross section realization along the river, on the base of DEM and satellite images, taking into account the change of slope, riverbanks' lines and contour lines. Once the cross sections are drawn, HEC-GeoRAS extracts river geometric and physical data from DEM. Figure 5 shows a cross section of river El Harrach that contains all the geometric characteristics to be used in simulation. Once the river is schematized and the cross sections are done, we export them to Hydraulic Model HEC-RAS.

4.4. Hydraulic modeling under HEC-RAS and flood hazard mapping under ArcGis

The hydraulic modeling focuses on the main river of Oued El Harrach watershed situated inside the administrative boundaries of the province of Algiers, where it crosses predominantly urbanized areas. The two main data to carry out this modeling are the geometric data of Oued El Harrach derived from HEC-GeoRAS processing and peak flows data derived from rainfall-runoff hydrologic modeling. We have exported the geometric data (River system schematic and cross section) to HEC-RAS, then, we inject the flows data of different return periods (frequencies) for simulation in steady regime. Prior to any simulation, it is necessary to calibrate the model by depths-runoff data observed from historical floods. Thus, to adjust the simulated water depths, it is necessary to vary the Manning's coefficient which is the parameter describing the frictions caused by river roughness, so as to correspondent the simulated depths to those observed. So, the model has been calibrated using available water depths and flows data for the two historical floods (25/01/1992) and (20/01/1994) measured in the two stations Rocher des pigeons and Baraki.

Table 4. Historical Floods Data (ANRG).

	Roger des Pigeons station (upstream) 021301		Baraki station (downstream) 021418	
Historical floods	Water depth (m)	Peak flow (m^3/s)	Water depth (m)	Peak flow (m^3/s)
25-01-1992	5.32	572	4.53	632
20-01-1994	5.30	568	6.70	1500

The validation has been done on the historical flood of 20 January 1994. The Maning's coefficients chosen are automatically computed by HEC-GeoRAS model under ArcGis on the basis of the land use extracted from high-resolution satellite image Quick Bird. These coefficients vary along

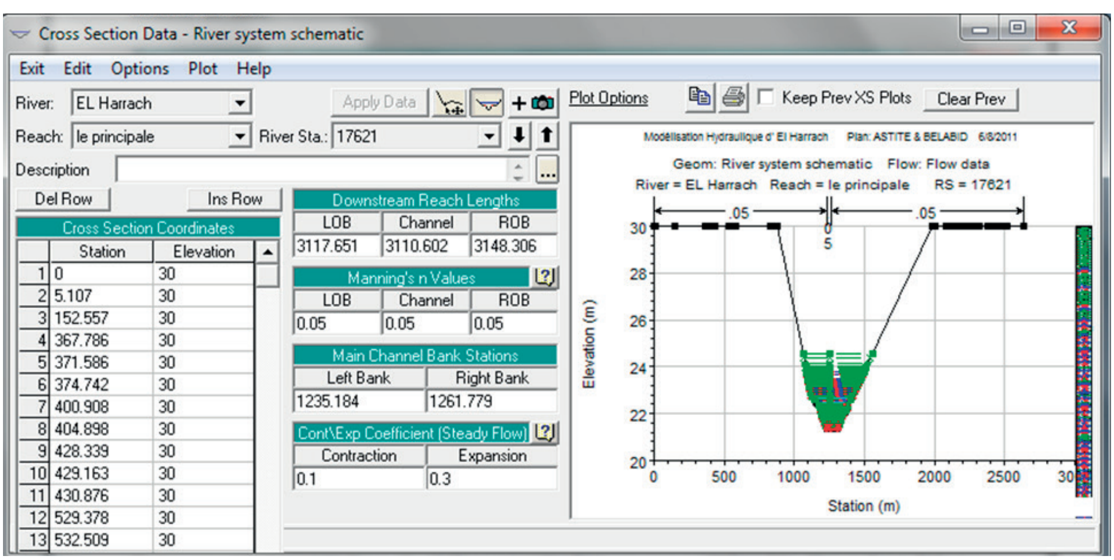

Figure 5. representation of cross sections under HEC-RAS.

the river. Once it is calibrated and validated, the model can be used for simulation in steady regime.

After the calibration and the validation of the model, we proceed to hydraulic simulation. The compilation of flows data derived from rainfall-runoff modeling and river geometric characteristics derived from HEC-GeoRAS processing, allowed calculating water depth of each peak flow in Oued El Harrach under the hydraulic model HEC-RAS. The modeling results are presented in Table 5.

Table 5. hydraulic modeling results of Baraki's station.

Return period (frequency)	Modeled peak flow (m^3/s)	Maximum water depth (m)	Minimum water depth (m)
T= 10 years	980	5.70	1.04
T= 20 years	1285	6.36	2.86
T= 50 years	1695	7.10	2.90
T= 100 years	1980	7.56	2.93
T= 200 years	2240	7.96	2.98

Two values of water depths have been obtained for every peak flow. These values vary from a period to another, according to the peak flow and the geometry of Oued El Harrach (cross section of the river). The simulated water depths corresponding to the observed water depths of historical flooding (flooding water depth of 1994 (6.70 m)) and the flooding of T20 years (6.36 m), confirm the calibration. Manning's coefficients and DEM are used as well as the reliability of hydraulic model HEC-RAS results.

The last phase of this work consists of the presentation of these depths over the land-use of river El Harrach, the result of these representations is flood hazard cartography by overflowing river on urban areas that are situated in the flood plain of Oued El Harrach. We carried out hazard maps according to the different frequencies (T10, T20, T50, T100, and T200) (Figures 6 to 10), as well as for referential flooding of 1994 (Figure 11).

In order to describe the lateral extent of these floods on urban environment, the results show that the risings of Oued El Harrach affect mainly urban and industrial areas as well as agricultural fields. The water depth rises from a period to another; it is low within frequencies of 10 (Figure 6) and 20 years (Figure 7) where it respectively reaches 5 m and 6 m, then, it passes to 7 m (50 and 100 years) (Figures 8 and 9) and it reaches 8 m within the frequency of 200 years. As for the spatial extent, it varies also from a period to another according to the peak flow, water depth and area topography. It is much larger within the two frequencies (T100 and T200) (Figures 9 and 10).

The spatial extent rising of these floods doesn't depend only on the different peak flows but also on the area topography that's in the form of a plain whose altitudes don't exceed 10 m. Adding, the contribution of the main seven reaches of Oued El Harrach. The floods spatial extent is more important on the right bank because of lands topography that doesn't exceed 6 m of altitude, the importance of the contributions of water and reaches sediments mass of river Oued El Harrach. The most affected municipalities on this bank are El Harrach and Baraki, exactly the neighbourhoods of "Les trois Caves". On the other hand, the spatial extent is less important on the left bank considering the lands topography which is higher than that of right bank. The affected municipalities are: Bourouba and Gué-de-constantine, more precisely Boumaâti neighbourhood. To these natural phenomena (peak flows, dense river network and low topography) we add human activities shown by uncontrolled urbanization owing to population growth increase and the setting up of big industry (petrol centre Naftal) on the two banks; which contributes to the increase of damages during floods. The present results confirm the hypothesis of the setting up of populations and activities in flood-risk areas, of which we find neighbourhoods and industrial estates which are completely established in flood-risk areas, the thing that justifies the scale of the damages caused.

The different maps show that the areas affected by the previous inundations are the same affected by the simulated inundations, namely: living areas, particularly Boumaâti and trois caves neighbourhoods, railway and road networks, industrial estates of Smar, El Harrach and Baraki, which shows the reliability of hydraulic modeling results.

The analysis of these maps can leads to the delimitation of vulnerable areas (for ex. Neighbourhoods of Trois caves, Boumaâti and the industrial estate of El Harrach) including population and properties, as well as the most affected municipalities (El Harrach and Baraki municipalities). These areas require special preoccupation because they

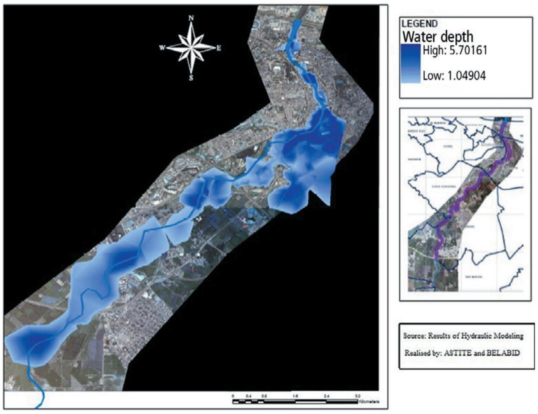

Figure 6. Flood hazard according to river level rising of the return period of 10 years.

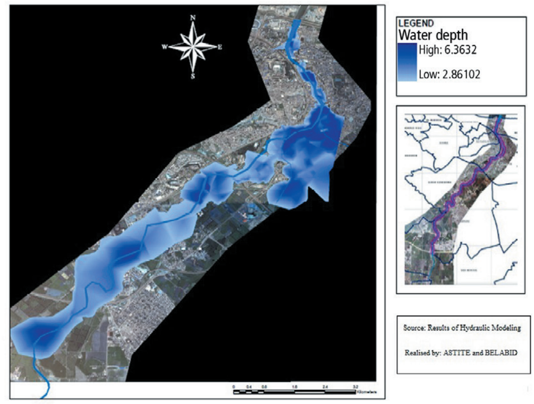

Figure 7. Flood hazard according to river level rising of the return period of 20 years.

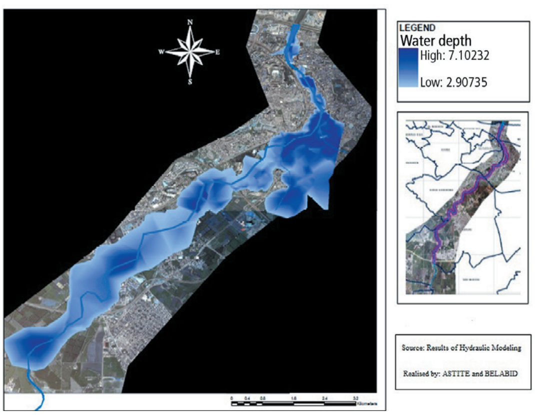

Figure 8. Flood hazard according to river level rising of the return periaod of 50 years.

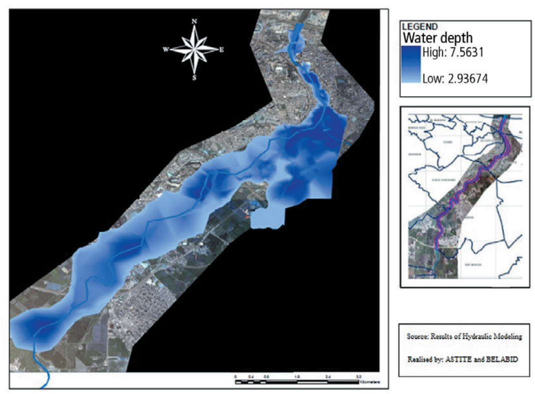

Figure 9. Flood hazard according to river level rising of the return period of 100 years.

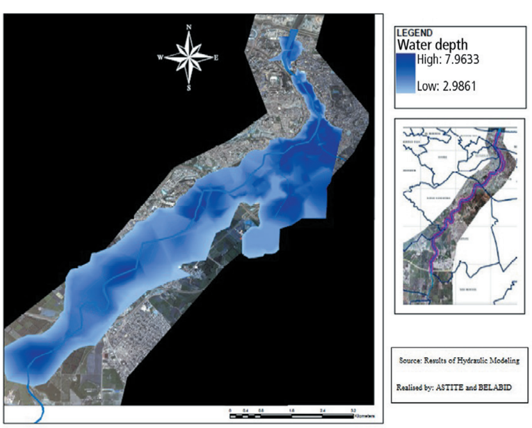

Figure 10. Flood hazard according to river level rising of the return period of 200 years.

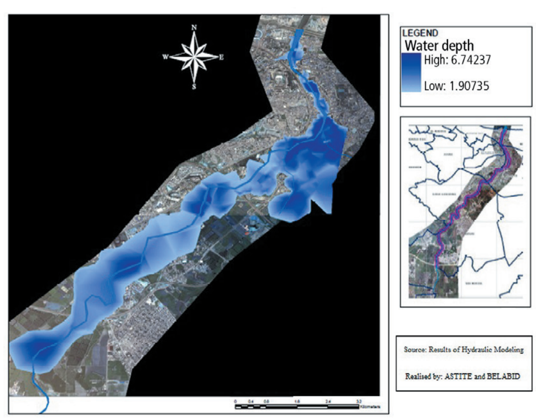

Figure 11. Flood hazard according to the referential rising of 1994.

were built on flood plains by self-builders without taking the risks of their planning into account (uncontrolled urbanization phenomenon)

On the basis of the present maps, we propose some preventive, prediction and management recommendations of flooding risk in study area:

- Delimitation of Flood-risk areas
- Integration of these areas in land-use plans
- The banning of construction in flood-prone areas
- Determine the factors increasing flood hazard
- Inform populations about the hazard surrounding them
- Evaluation of hazard consequences
- Inform big factories of industrial estates about the expected risk to prepare protection against theses floods
- Evaluation of property damages (industrial estates, housing, equipments, railway and road networks)
- Assistance and intervention planning
- Knowledge of water depths per zone, i.e in such zone water will reach such depth
- Inform authorities and local community about the flood prone areas

Finally, the results of this study represent a management tool for decision makers in several fields such as town and country planning, disaster-prone areas regulations, crisis management and assistance organization.

5. Conclusions

River El Harrach is one of the most important rivers in Algeria; it has an area of 1236 km^2 covered by its watershed, and a length of 51 km. In its downstream part located at Metidja plain, it crosses the completely urbanized areas where it was liable to many inundations causing considerable human and properties damages, these damages resulted from growth population and the spreading of the municipalities over the natural space of this river. This spreading doesn't take disaster-prone areas, particularly flood-risk areas into account, because of the absence of plan of determination and banning of construction in these vulnerable areas in terms of properties and humans. The aim of this study is to carry out flood hazard cartography by overflowing river; this cartography may help to work out a prevention plan against inundations for the management and the urbanization planning.

The methodological approach adopted, focused on the hydraulic modeling under the model HEC-RAS and the cartography under the Geographic Information System ArcGis. The hydraulic modeling results allowed calculating water depths of different peak flows. The combination of hydraulic modeling results with land-use under ArcGis made flood hazard maps result according to different frequencies (T10, T20, T50, T100 and T200). This mapping allowed us defining the flood spatial extent on urban environment and delimiting flood hazard areas where it shows that the most affected areas are those built 40 years ago, anarchically, without considering the risks in the planning and the management of space. As it also shows that the spatial extent augmentation of these floods does not depend only on the several peak flows, but also on the area topography that's in the form of a plain whose altitudes don't exceed 10 m. The adopted methodology will allow to expect the future floods and to know the areas affected by inundation phenomenon which permit to contribute to the floods risks management (prevention, prediction and alert). From this hazard maps, it is possible to make risks cartography by adding vulnerability maps.

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