Flood Hazard Spatialization Applied to The City of Batna

A Methodological Approach

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Abstract—**Flood flows can cause destruction to properties and infrastructure or even cost human lives. Batna is an Algerian city that is highly exposed to the risk of flooding, with an average of one flood every three to four years. The current methods utilized to analyze flood hazards are limited to the hydrology of the watershed. Limiting the analysis of flood hazards could mislead the decision-makers from proper management of such risks. The objective of the current study is to propose a simplified flood hazard model called HEC RAS-DTM (Hydrologic Engineering Centers River Analysis System (HEC RAS)-Digital Terrain Model (DTM)) and to evaluate it utilizing data gathered from the hydrological context and the hydraulic modeling of Batna city. The model entails two distinct phases. Initially, it attempts to use descriptive statistical methods based mainly on frequency analysis, which consists of studying flood flows in order to determine the probability of future flood occurrence. The analysis of the hydrological context of the city of Batna has revealed that peak flows from stream floods have been predicted at various return periods. Subsequently, HEC RAS was deployed to produce hydraulic modeling in order to extract the water heights and speeds corresponding to these expected flows. These data, along with DTM, are crucial for the spatialization of flood hazards. The hydraulic modeling and simulation using HEC-RAS and Geographic Information System (ArcGIS) of water flow at the two main valleys, Oued Batna and Oued El Gourzi, allowed predicting the extent of flooding that could occupy a large part of the city. The mapping of the flood hazard revealed the sectors that would be most exposed. The results obtained from the suggested model confirm that a significant portion of the city of Batna remains vulnerable to floods in relevance with the predicted flood return periods. The suggested model has indicated significant growth in flood locality. Additionally, the model was proved to be efficient for the analysis of flood flows, and it could easily substitute conventional analysis methods. Further studies or investigations are advised in order to replicate the study in different contexts. The article entails suggestions for properly managing flood risks. Future studies on flood risk alleviation in Batna city could be likewise considered.**

Keywords-HEC; RAS; DTM; flood; flood hazard; spatialization; Batna

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I. INTRODUCTION

Flood flows can cause significant damage to property, infrastructure, or cost human lives [1]. It is advocated that the most common floods happen near rivers or streams with a heavy rainfall over a catchment area acting as a water source [1]. Flood analysis is advocated because it allows hydrologists and statisticians to estimate the probability of future flood incidents. Flood analysis is crucial because it determines the hydraulic structures of a given region [2]. Flood analysis results can orient decision-makers to improve flood hazard readiness. Moreover, flood analysis is vital towards proposing strategies for flood alleviation through the introduction of project plans. Several numerical flood analysis models have been proffered using the probabilistic approach to flood management and planning. A stochastic model has been developed in order to analyze the annual stream flow of Karkheh River in Iran for flood forecasting. The obtained results indicated that the ARIMA model was adequate for flood analysis in Karkheh River and for the prediction of the series in a short time in the future [3]. Similarly, a stochastic model has been established for reducing economic floods risk in Yewa sub-basin, by adjusting maximum annual momentous discharge into four probability distributions. The model generated from the Weibull probability distribution proved to be useful to enhance sustainable development by reducing economic flood damages in the sub-basin [4]. The volume of fluid modeling approach has been investigated to understand the role of vegetation in an energy reduction of flood flow. The results communicated the vitality of an optimum vegetation design for the protection of structures. Furthermore, the study has suggested the development of a numerical model with various ground conditions to find minimum optimum building distance and to reduce flood destructions with vegetation [1].

Authors in [5] investigated the impact of different Digital Elevation Model (DEM) resolutions on the topological attributes and simulated runoff and the sensitivity of runoff parameters. ArcGIS was utilized to delineate the watershed and streamlines. The hydrological analysis was carried out using the Soil and Water Assessment Tool (SWAT). The results communicated the change in sensitivity of runoff parameters, watershed surface area, and elevations under different DEM resolutions. Using different DEMs resulted in a change of distribution of slopes. As a conclusion, surface parameters were most affected. The findings of this study indicated that researchers may use DEMs with coarser resolutions in order to reduce computation time. Hence, the resolution of data is a sensitive factor in environmental modeling. A series of catastrophic floods that have hit Algeria recently remind local residents and public authorities of the omnipresence of such risks. The latter is attributed to the change in land use through anarchic urbanization [6]. Flood hazards have caused significant damage due to the concentration of goods, activities, and people in submersible areas during the previous decades.

Like many Algerian cities, Batna is one of the agglomerations that present a high risk of flooding, with high floods occurring averagely every three to four years. The vulnerability of the city of Batna is linked to its location. It is situated in a slightly sloping site, and is crossed by two valleys. Additionally, Batna city is surrounded by a very rugged terrain of mountains. Despite the progress achieved since the promulgation of Law 24-05 2, the local actors of the city remain in search of controllable and reliable methodologies in order to objectively assess the magnitude of this hazard. Most current flood risk analysis methods are limited to hydrological studies. Several attempts have been developed to map the flood hazard of the city of Batna. Authors in [2] attempted to delineate the flood hazard through a hydraulic modeling approach. The flood hazard has been mapped through a hydraulic modeling method. The model was based on the use of the Geographic Information System (GIS) to perform a spatial analysis about the flood hazard limits. However, there is a need to further develop models to address the lack of effective flood risk management decision support tools for local communities.

A methodology has been developed to calculate valley floods in Algeria based on hydrograph calculation formulas. The objective was to propose a calculation formula adapted to the Algerian hydrological context with the aim of mastering and understanding the spatial and temporal variations of rains and flows. It is worth mentioning that this research was focused on the hydrological part because it was intended for engineers and planners in the field of hydraulic design [7]. Contrastingly, the current research aims to provide local actors with a flexible methodology to map the flood risk in well-defined areas. The main objective of the present study is to develop a flood hazard model of the city of Batna and to assess the model based on data gathered from the hydrological context and the hydraulic modeling of the city of Batna. Thus, the introduced approach, called Hydrologic Engineering Centers River Analysis System - Digital Terrain Model (HEC RAS-DTM) has the objective of spatializing the flood hazard through the use of modeling and mapping tools. Additionally, the study aims to suggest solutions towards the proper management of future floods and to implicate the study findings towards a better flood risk alleviation.

II. Study Area

A. Location

The studied area has been delimitated according to two primary location criteria: The first criterion entails the physical location of the area. It describes the distribution of the large morphological sets and major topographical features of Algeria. The second criterion is linked to the hydrological location. The latter aids illustrating the location of the study area into the large watersheds according to the National Agency for Hydraulic Resources (ANRH) classification [8]. Geographically speaking, the studied area is located precisely at the convergence of the two major topographic sets of Algeria. Namely, the Tellien Atlas represented by the Hodna chain, and the continuation of the Saharan Atlas represented by the massive Aures [9] (Figure1). Hydrologically speaking and as illustrated in Figure 2 [8] and Figure 3 [9], the studied area is a part of the vast watershed of Constantine highlands. The aforementioned watershed is identified by number 7 according to the codification of the National Agency for Hydraulic Resources. The southwestern boundary of the watershed of Batna city borders with the vast watershed of Chott Melhir (number 6) on a length of 25km. The northwestern boundary borders with the significant Chott El Hodna watershed (number 6) over an approximate length of 7.5km.

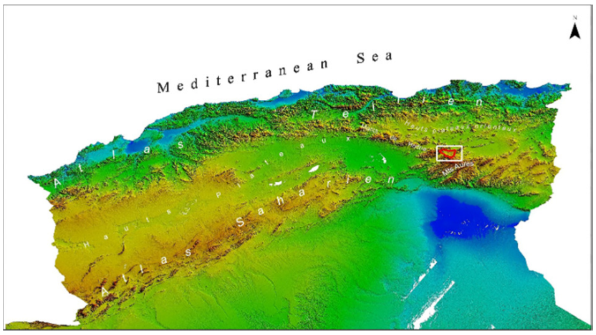


Fig. 1. Geographical location of the watershed of Batna city (source: authors using DTM on images from the National Institute of Cartography and Teledetection)

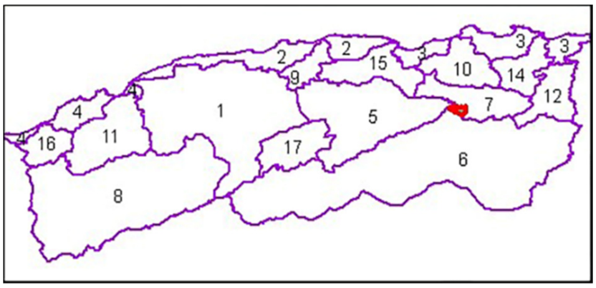


Fig. 2. Hydrological location of the watershed of Batna city (source: authors using DTM on images from the National Institute of Cartography and Teledetection)

B. Topography

As outlined in Figure 7, three main elements of the landform constituting Batna city watershed framework have been identified.

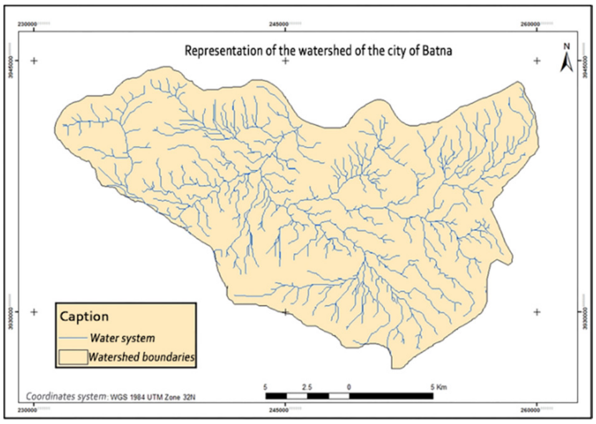


Fig. 3. Representation of the watershed of the city of Batna (source: authors using DTM on images from the National Institute of Cartography and Teledetection 2015)

1) The Mountain Range

The mountains surrounding the city of Batna are part of the Hodna Mountains. The range is constituted by Meghoua mountain, Boumerzoug mountain, and Kessrou mountain in the west side of the city. In the north, Azab mountain covers the city. In the south of the watershed, the mountain range is extended through the Aures massif, which is identified by the mountain of Ich Ali.

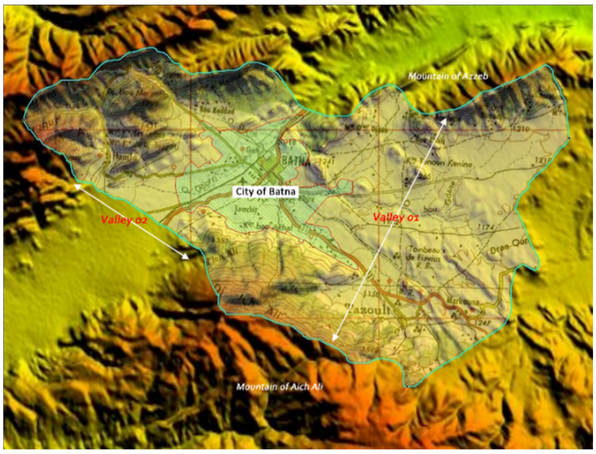


Fig. 4. Batna city watershed relief map (source: authors using DTM on images from the National Institute of Cartography and Teledetection)

2) The Valleys

Two valleys can be distinguished which are intersecting the urban perimeter levels of the city of Batna. The first valley is located in the north-west south-east axis of the city and covers a wide area in the south-east. The valley is limited by Ich Ali mountain in the south and by Azzeb mountain in the north. It tightens at the centre to become very narrow at the north-west at the level of the Meghoua and Boumerzoug mountains.

From a hydrological point of view, the south-eastern part of this valley occupies a very important surface in comparison to the surface it drains in the north-western part. The second valley is oriented north-east south-west. It is geometrically straight. It divides the mountain ranges into two blocks, the east and the west block. It is probable that the shape of this valley is attributed to the geological structure and tectonics of the study area as illustrated in Figures 4 and 5 [9].

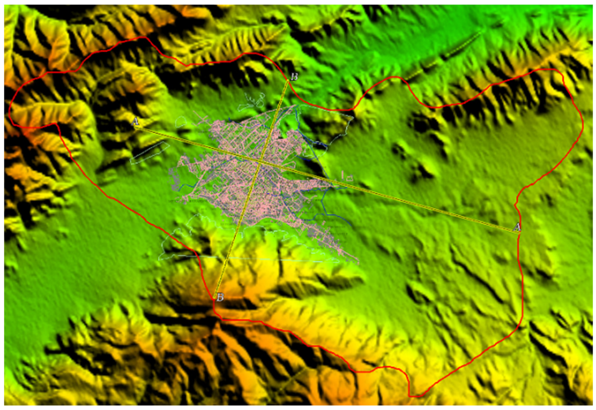


Fig. 5. Topography of the watershed of Batna city (source: authors using DTM on images from the National Institute of Cartography and Teledetection)

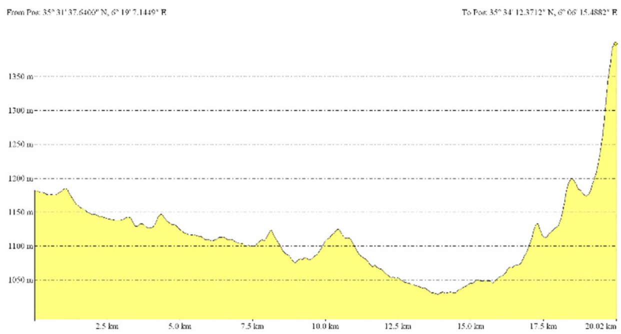


Fig. 6. Watershed pofile using ArcGis 10.3 software

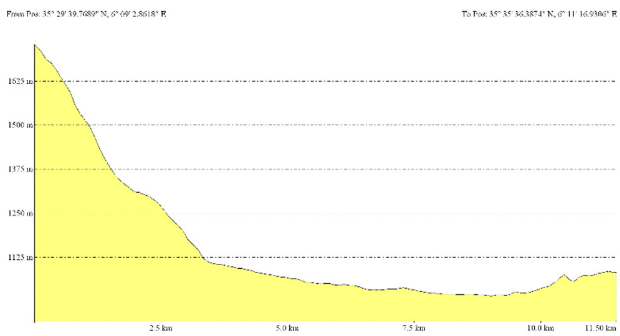


Fig. 7. A-A profile using ArcGIS 10.3

3) Watershed Depression

The lowest relief in the watershed is called depression watershed. It is buckled by the mountain belt, and it is located at the bottom of the mountain ranges. Precisely, it occupies the limit of the perimeter of the city of Batna. Hydrologically speaking, this depression watershed represents the lowest elevation point of the two valleys described above. A fact which needs to be highlighted is that this depression watershed is located at the convergence area of all the valleys in the watershed where the rainwater concentration is extreme.

C. Altitude Class and Slope System

A map of the classes of the altitude has been prepared to translate the relief's altimetry value and to explain the allure of the watershed relief numerically. As illustrated on the altitude map (Figure 8) [9], it can be perceived that the altitude values range from 990m to over 2000m. High values characterize the mountainous massifs, ranging from 1200 to 2000m. Spatially speaking, this altitude range occupies a comparatively small area compared to the entire watershed.

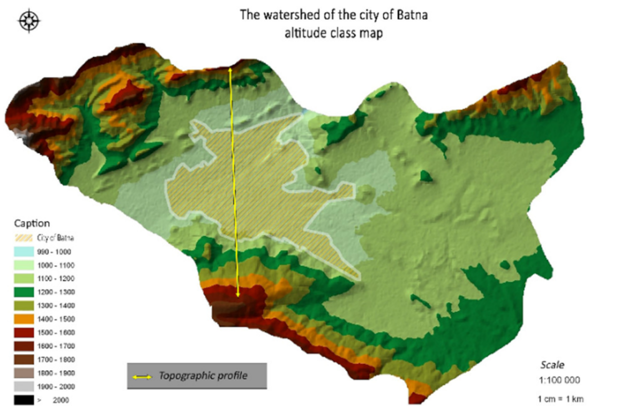


Fig. 8. Altitude class of Batna city watershed (source: authors using DTM on images from the National Institute of Cartography and Teledetection)

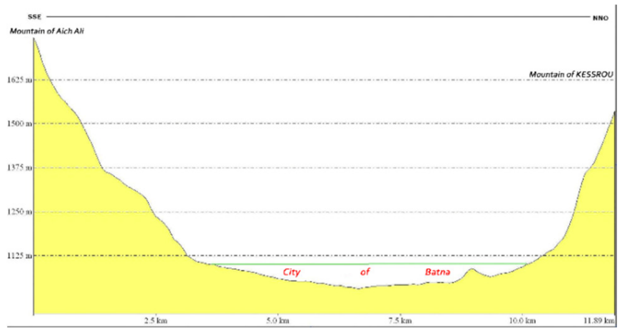


Fig. 9. Topographic profile according to the altitude class of Batna city

Altitude values below 1200m present the bottom of both valleys. They constitute the majority of the surface area of the watershed. The city of Batna, with its current perimeter, is constructed between the contour lines of 990 and 1100m. A particular fact to which special attention should be paid is the extreme unevenness on topographical plans of the slopes at very short distances as illustrated by the example of the slopes of mountain Ich Ali exposed to the north. This situation is expressed by distinct steep topographic slopes, which significantly promote surface water flows by reducing the time of water concentration. The topographic profile in Figure 9 expresses the relief aspect [9]. The analytical reading of the slope map in Figure 10 [9] highlights a significant fact, which is the transition from one slope system to another. In some slopes, there may be a passage from the very steep slope directly to an insensitive slope, which may explain the brutality of the hydrological regime. The city of Batna is located almost entirely in an area with a slope of less than 4%. Table I presents the watershed distribution in altitude class [10].

TABLE I. WATERSHED DISTRIBUTION IN ALTITUDE CLASS

Altitude levels		Area km^2	Area %	Cumulated km^2	Cumulated %
992	1040	7.2	2.43	7.17	2.43
1040	1090	45.9	15.57	53.08	18.00
1090	1140	51.4	17.41	104.44	35.41
1140	1190	56.0	18.97	160.39	54.38
1190	1240	40.8	13.83	201.17	68.21
1240	1290	22.9	7.76	224.05	75.96
1290	1340	14.9	5.04	238.92	81.00
1340	1390	13.7	4.64	252.60	85.64
1390	1440	11.1	3.75	263.65	89.39
1440	1490	8.3	2.80	271.91	92.19
1490	1540	6.5	2.21	278.44	94.40
1540	1590	5.2	1.76	283.64	96.16
1590	1640	4.1	1.39	287.72	97.55
1640	1690	2.9	0.97	290.59	98.52
1690	1740	2.4	0.81	292.98	99.33
1740	1790	1.0	0.33	293.95	99.66
1790	1840	0.5	0.17	294.44	99.83
1840	1890	0.3	0.10	294.73	99.92
1890	1940	0.1	0.03	294.82	99.95
1940	1990	0.1	0.03	294.89	99.98
1990	2040	0.1	0.02	294.95	100.00

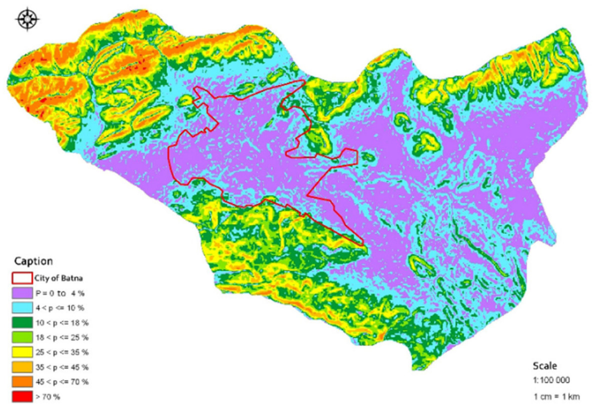


Fig. 10. Slop map of the watershed of Batna city (source: authors using DTM on images from the National Institute of Cartography and Teledetection)

D. Delimitation

The delimitation of the watershed of Batna city is accomplished using the Shutter Radar Topography Mission (SRTM3) data of a hydrological spatial analysis by the GIS under ArcGIS at an enforceable point upstream from the boundary of the urban area of the city.

E. Surface and Primeter

The treatment by the Arc toolbox tool of ArcGIS has indicated that the watershed of the city is below the perimeter of 85,175km and an area of 295.52km^2. As the catchment area is the receiving and feeding area for the streams, the flows will be partly connected to its surface. The catchment area is calculated automatically by the ArcGIS using the geometric calculation tool (Figure 11) [9]. The watershed is the reception area for precipitation and feeding courses of water, the flows would be partly related to its surface. The watershed area is automatically calculated by ArcGIS using the geometric calculation tool.

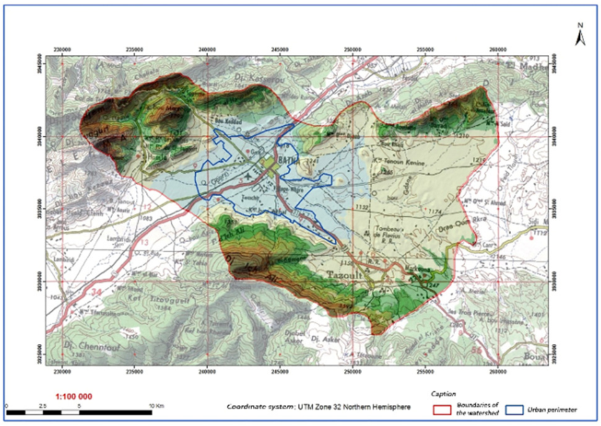


Fig. 11. Boundaries of the watershed of Batna (source: authors using DTM on images from the National Institute of Cartography and Teledetection)

F. *Average Slop of the Watershed*

The average slope is a significant characteristic which provides essential data about the topography of the watershed. It is considered as an independent variable. It gives a reliable indication of the path time of direct runoff. Additionally, it indicates the concentration-time and directly influences the peak flow of the rainfall. Several methods have been used to calculate the average slope of a watershed. Most of these methods are based on the reading of an actual or approximate topographic map. The calculation of the average slope, as well as their exposure (slope orientation), could be easily accomplished based on numerical data representing the topography of the watersheds using software Digital Model of Altitude ArcGIS and Global Mapper.

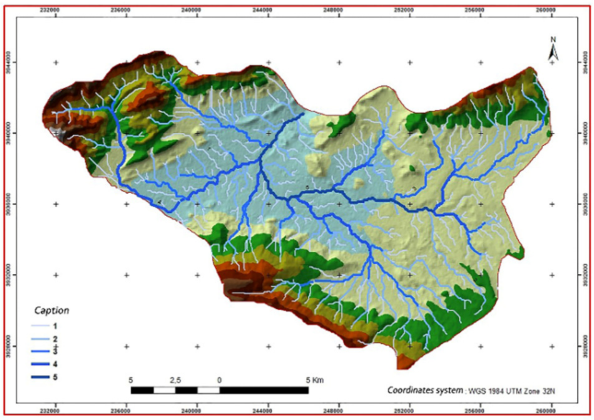


Fig. 12. Hydrographic network of the watershed of Batna with flow order (source: authors using DTM on images from the National Institute of Cartography and Teledetection)

G. *Hydrographic Network*

The watershed of the city of Batna is drained by several valleys as Figure 13 demonstrates [11]. These valleys are:

- Oued El Gourzi valley: it is the most critical watercourse crossing the study area. It occupies a length of 10.1km.
- Oued Batna valley: it crosses the city over a length of 3014m. It starts from the south east (Zmala), then it joins the belt canal to which its length is around 3505m. Finally, it pours into the Oued El Gourzi.
- Oued Tazoult valley: it also crosses the city over a length of 3433m. It is independent of Oued Batna, but it joins it at the level of the construction of the intonation located in the forage Park. Then, it starts again in a Talweg of a 2584m long.
- Oued Bouzourane valley: this valley represents a flood risk on the city (northern part) where the construction of the protection gallery and the collection of stormwater are located. It joins Oued El Gourzi valley further north.
- Oued Sgan Valley: It crosses Kchida from the northwest to the south east where it joins Oued El Gourzi valley at the level of the belt canal (Oued Bouziane valley).

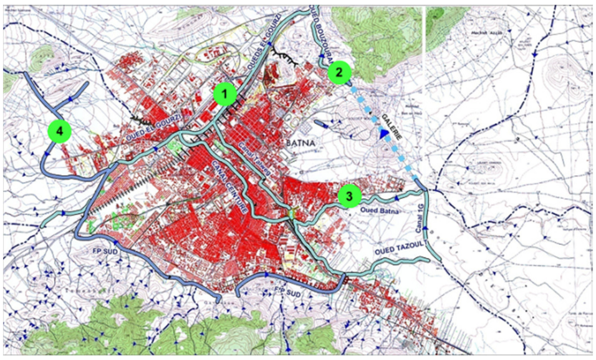


Fig. 13. Main valleys crossing Batna city (source: authors using DTM on image from the Hydraulics Management, Batna City)

Fig. 14. Pictures of the main valleys crossing Batna city

The city of Batna is crossed by two main valleys, the valley of Oued Batna with a length of 6519m, and the Oued Tazoult valley with a length of 6017m. The structure developments carried out on these valleys are concessions of trapezoidal and rectangular sections, in paving, concrete, concrete retaining walls, and masonry support. There are cases where only one shore is found to be landscaped, while the other is not. These valleys are characterized by irregular seasonal flows, which can be significant and cause devastating floods such as the ones that occurred in November 2005, April 2006, July 2008.

III. TOOLS AND METHODOLOGY

As mentioned above, the methodology adopted in this analysis is built around a combined approach called HEC RAS–DTM. This approach, as mentioned above, takes place into two distinct phases. Initially, the analysis attempts to acquire data from a hydrological study that will allow subsequently obtaining the flows of the floods, their return periods, and most importantly, their submerged duration. Then, a hydraulic study is carried out in order to highlight the heights and the water speeds corresponding to these expected flows. These data are vital for the spatialization of the flood hazard that endangers the city of Batna. Cartography is therefore based primarily on the numerical modeling of the results obtained in the first two stages using the HEC RAS 4.0 as an instrument of hydraulic modeling, and the DTM under ArcGIS 10.3 derived from the geographical information system "GIS" as a tool for the cartography of the exposed areas. In other words, the HEC-RAS model will demonstrate its ability to graphically represent the extent of the floods and the DTM derived from the GIS will allow a good spatialization of the parts of the city exposed to this risk.

A. Hydrological Study

The hydrological study will be adopted to predict the flood flows of the valleys corresponding to different return periods. It is intended to predict peak flood flows of valleys suitable for different return periods. Thus, the methodological choice was to focus on frequency analysis as a method of prediction. The latter consists of studying past events in order to identify their probabilities of future occurrence [12]. The purpose of this statistical method is to determine the return periods. It seems logical to go through the following steps:

- Collect a set of data of the peak rates recorded by the local station of the city of Batna.
- Classify and order these data.
- Deploy the principles of descriptive statistical laws to condense information using standard values such as mean, standard deviation, etc.
- Analyze and accommodate the results to the most suitable probabilistic model that describes the probability of a given peak flow rate.

In this respect, various statistical distribution laws are used for frequency adjustment. The most frequent are the normal law, lognormal, and the law of Gumbel [13]. Thus, at the end of the hydrological context analysis, the following data have been concluded:

- Maximum daily rains' amount.
- Short-duration rains' intensities.
- Peak flood flows.
- Flood volume.

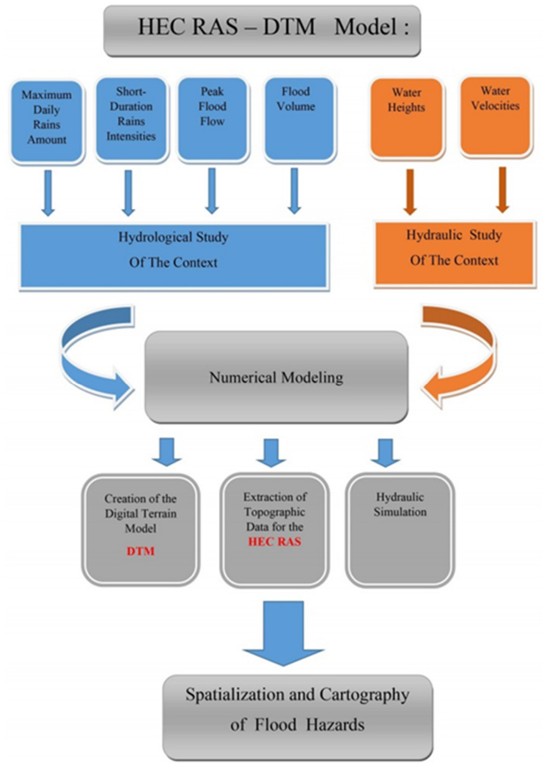


Fig. 15. Spatialization of flood hazard using the HECRAS-DTM model

B. Hydraulic Modeling

The hydraulic study consists of having the water heights corresponding to the flows previously planned. Accordingly, the results of the hydrological study will be correlated with other parameters such as the geometry, the slope, and the roughness of valleys. These data will be employed as input in the hydraulic model HEC-RAS in order to obtain the corresponding water slides (output). The valleys considered for this analysis are Oued Batna and Oued El Gourzi. The simulation using HEC-RAS of the water flow at the level of these valleys is conducted through the following steps:

- Creation of the Digital Terrain Model (DTM) in order to prepare the topographic data for the HEC RAS.
- Extraction of topographic data for the HEC RAS.
- Hydraulic simulation.
- Spatialization and cartography of flood hazards.

IV. RESULTS AND DISCUSSION

A. Hydrological Study

On conducting the present study about the hydrological context of the city of Batna, no weather generator [15] has been used. The latter uses existing weather readings to generate synthetic series of weather data such as the Advanced Weather GENerator AWE-GEN model [13]. The used data consist of:

1) Maximun Daily Rains

In Algeria, it is verified that the maximum annual daily rains according to the Gumbel law range from 53.3mm for a return period of 10 years to 77.40mm for a centennial period (Figure 16) [10].

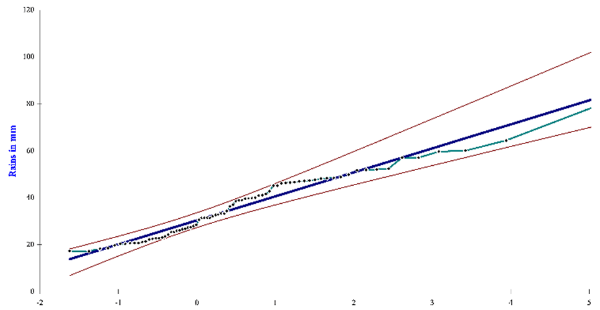


Fig. 16. Maximum daily rainfall adjustment according to Gumbel law at Batna station

By adopting (1), the maximum daily rain quantities (at a given frequency) at Batna will be deduced. These data are summarized in Table II [10].

$$Pt = Pjmax\% * (t/24)b \quad (1)$$

where *Pt* is the rain corresponding to a time period, *Pjmax%* is the maximum daily rain frequency given to Batna, and *b* is a climatic parameter equal to 0.30 for the Batna region.

TABLE II. MAXIMUM DAILY RAINFALLS AT BATNA

Return period	Frequency	U. Gumbel	Pjmax
2 Years	0.5	0.37	34.1
5 Years	0.8	1.50	45.7
10 Years	0.9	2.250	53.3
20 Years	0.95	2.970	60.7
50 Years	0.98	3.902	70.2
100 Years	0.99	4.600	77.4

2) Short-Duration Rain Intensities

To calculate short-duration rain intensities, a study entitled: Frequency Analysis of the rains of Algeria conducted by the National Agency for Hydraulic Resources (ANRH) [10] has been adopted. The study has collected data based on three parameters: intensity, duration, and frequency. Taking into consideration the maximum rain amounts at Batna station, this study has allowed calculating rains intensities in mm/hour for different frequencies and for different durations as shown in Table III [10].

TABLE III. RAIN INTENSITIES PER HOUR IN BATNA STATION (MM/H)

Return period	15min	30min	1h	2h	3h	6h	12h	24h
2 Years	34.7	21.4	13.1	8.1	6.1	3.7	2.3	1.4
5 Years	46.5	28.6	17.6	10.8	8.2	5.0	3.1	1.9
10 Years	54.2	33.4	20.5	12.6	9.5	5.9	3.6	2.2
20 Years	61.7	38.0	23.4	14.4	10.8	6.7	4.1	2.5
50 Years	71.4	44.0	27.1	16.7	12.5	7.7	4.8	2.9
100 Years	78.7	48.5	29.8	18.4	13.8	8.5	5.2	3.2

3) Peak Flow

The study of peak flood flows is based on rainfall data, namely maximum daily rainfall for more than 400 rainfall stations [7]. Concerning the current study, the following equation developed in [5] will be deployed to calculate the different peak flows of the various return periods of the rivers and ungauged valleys of Algeria:

$$QPT = \frac{16.7[A + B\log(T)]aT\lambda S}{(tc+1)n} \quad (2)$$

where *QPT* is the Peak Flow Rate, λ the flow reduction coefficient as a function of the watershed area growth, *S* is the watershed area in km², aT is the shock coefficient, *tc* the concentration time in minutes, *A* and *B* are geographical parameters characterizing the maximum intensity of annual rainfall (*A*) and its variation inter annual (*B*), *T* is the return period, and *n* is a coefficient equal to 0.73 (average annual rainfall ≤400mm). Regarding peak flows, the calculation formula developed in [7] revealed that these values will double to reach 304.00m^3/s for a return period of 100 years, which is enormous compared to the 155.00m^3/s for a 10-year return period. The following table summarizes the peak flows according to their return periods [10].

TABLE IV. PEAK FLOWS ACCORDING TO RETURN PERIODS

Return period	Peak flow (m^3/s)
2	70
10	155
20	197
50	284
100	304

4) Flood Volume

The flood volume, expressed in m^3, will then be given by (3) for which *tc* is expressed in minutes:

$$V = 60Q\max \times tc \quad (3)$$

where *Q*max is the maximum flood flow rate of return duration T in m^3/s and *V* is the flood volume (m^3).

It has been noted that a significant quantity estimated at 171,456m^3 is to be expected for a period of one century, against almost half for the 10-year return period. These data were used to predict the flows of valley floods corresponding to different return periods.

B. Hydraulic Modeling by the HEC-RAS

The objective of a hydraulic study is to obtain data related to water heights corresponding to the previously predicted flows. However, the latter has to be combined with data from the hydrological context in order to establish a reliable input database in the HEC-RAS hydraulic model. These data are assembled in order to have an output of the corresponding water slides taking into consideration the geometry of the city crossing streams, the longitudinal slope, valley bed roughness, and its banks in the various calculation points. In this aspect, and in order to carry out the analysis, HEC-GEORAS application has been utilized. The application has the advantage of offering better compatibility between HEC-RAS and GIS.

Additionally, it allows the import of cross-sections from Arc View to HEC-RAS. This option would eliminate the tedious manual handling of cross-sections. The HEC-GEORAS application also offers the possibility to export simulations and to display them in 2D and 3D images in the Arc View [6]. All data and information collected on the study area and the cross-checking of the results clearly show that the source of the flood risk in the city of Batna comes mainly from the floods of Oued Batna and Oued El Gourzi valleys. Oued Batna includes two tributaries, Oued Azzeb and Oued Tazoult. This valley drains the southern part of the Batna catchment area. Oued El Gourzi with its tributaries drain the west and north of the catchment area. The analysis of the flood hazard mapping by HEC RAS hydraulic modeling approach shows that the flood spot increases from the decennial flood to the centennial flood. From the decennial flood, it begins to occupy the major bed of the valleys and penetrates into the southern part of the city from the confluence of the two valleys (Azzeb and Tazoult). Then, it slips towards the central part of the city by joining the other flood of Oued El Gourzi coming from the west to meet its trajectory and sinks towards the eastern part of the city.

1) DTM Creation

A DTM is a representation of topography or altimetry of a terrestrial area in a form suitable for use by a digital computer. The version 10.3 of the ArcGIS software offers the possibility of hydrological treatment. The ArcGIS 3D Analyst extension also encompasses tools for the creation of exact surface models, commonly called Triangle Irregular Network (TIN). These data are extracted directly from the SRTM database, and are identified as the topographic matrix and vector files provided by two United States agencies: the National Aeronautics and Space Administration (NASA) and the National Geospatial-intelligence Agency (NGA).

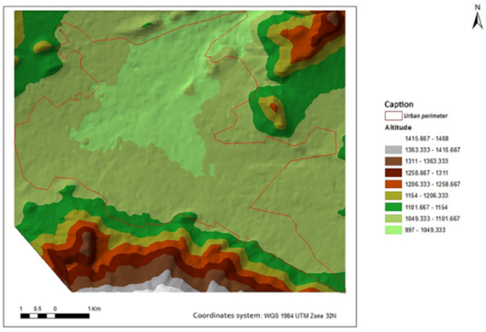
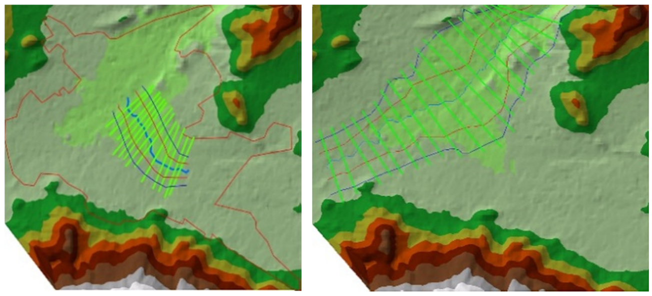


Fig. 17. Creation of DTM of Batna city watershed

The conversion using the ArcGIS Arc toolbox tool from the raster SRTM to TIN has given us the DTM model of the city of Batna for the various simulations projected under the Universal Transverse Mercator coordinate system (UTM zone 32) using the World Geodetic System (Datum WGS 1984), provides us with Figure 17.

2) Topographic Data Extraction for HEC RAS

Once the DTM-TIN is created, the geometry of Oued Batna and Oued El Gourzi valleys can be easily created through the use of the HEC GeoRAS interface, which is a program compatible with ArcGIS. The import folder is created from a series of RAS themes such as The Stream Center Line, the Main Channel Banks, which include Flow Path center lines, Cross-Sectional Cut Lines, Land Use, Ineffective Flow Areas, and Storage Areas. In this approach, the cross-section is the primary geometric element. It is plotted on the DTM and must include specific features to be representative. The profiles shall be perpendicular to the direction of the water flow. Thus, the flow directions in the major stream bed are not always well known. In Figure 18 we can see the main RAS themes created by HEC GeoRAS using the TIN DTM of Oued Batna and Oued El Gourzi valleys.



(a) (b)

Fig. 18. Extraction of geometric data using HEC GeoRAS of the valleys Oued Batna and Oued El Gourzi

3) Hydraulic Simulation

After introducing the watercourse geometry, the next step is to specify the flow rates used to calculate the flow patterns. For this purpose, hydraulic simulation was initiated in a gradually varying regime with the flow values. The flow values were obtained by adjusting the series of flows recorded at the hydrometric station of Batna corresponding to return periods of ten, twenty, fifty, and one hundred years. Thus, one can switch the hydraulic simulation properly by using the application of the steady flow simulation. This choice is well justified since the permanent name flow necessarily needs the flood hydrograph, an information that is entirely missing. The topographical survey of the valleys during that cross Batna attests that the latter is located in a flat area whose altitude ranges between 997 and 1049m over a distance of about 7km. Once the import file is available, the HEC RAS exports it using the Geometric Data command and displays the window as indicated in the print screens of Figures 19-20.

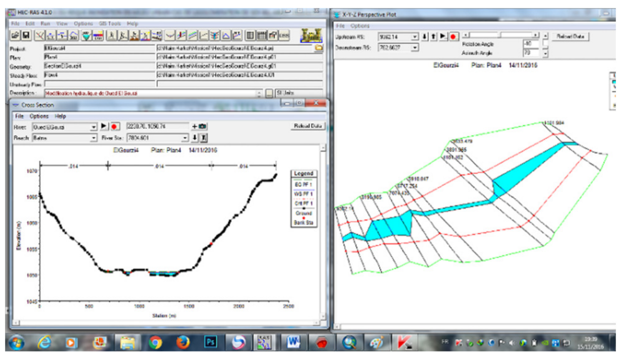


Fig. 19. Geometry of Oued El Gourzi valley using the HEC RAS software

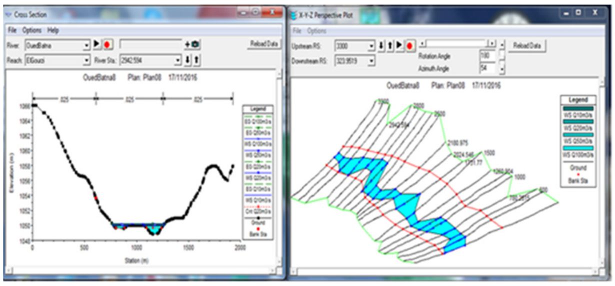


Fig. 20. Oued Batna valley geometry using HEC RAS software

4) Flood Hazard Spatialization (Cartography)

The final stage consists of the cartography of the results drawn from the hydraulic modeling in order to determine the hazard zones. Once the simulation is realized, the simulation results are exported to the ArcGIS using the HEC GeoRAS (postRas) in order to delineate the flood areas, which appear as blue spots. The following figure represents the final delineation of the flood area after the simulation file has been exported:

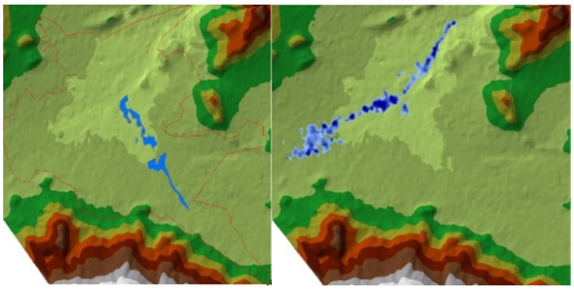


Fig. 21. Spots representing flood areas on Oued Batna and Oued El Gourzi valleys based on a 100-year frequency flow - HEC GeoRAS (postRas)

C. Result Interpertation

Initially, the ten-year flood could extend to occupy the major bed of the valley of Batna, and then continue its flow towards the southern part of the city from the conflux of the two valleys (Azzeb and Tazoult valley). Then, it slips towards the central part of the city by joining the flood of Oued El Gourzi valley coming from the West. Eventually, it sinks towards the Eastern part of the city. Thus, the most exposed areas are the north entrance of the city on the side of Kadri real estate, Kechida, the central city, Zmala, Tazoult road, and the University Hospital. Figure 22 represents the hazard map.

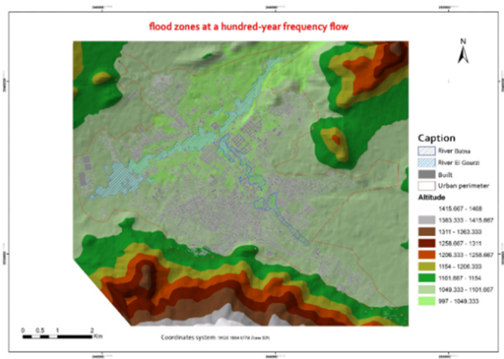


Fig. 22. Map of the flood hazard of the city of Batna obtained using- Hec RAS – DTM

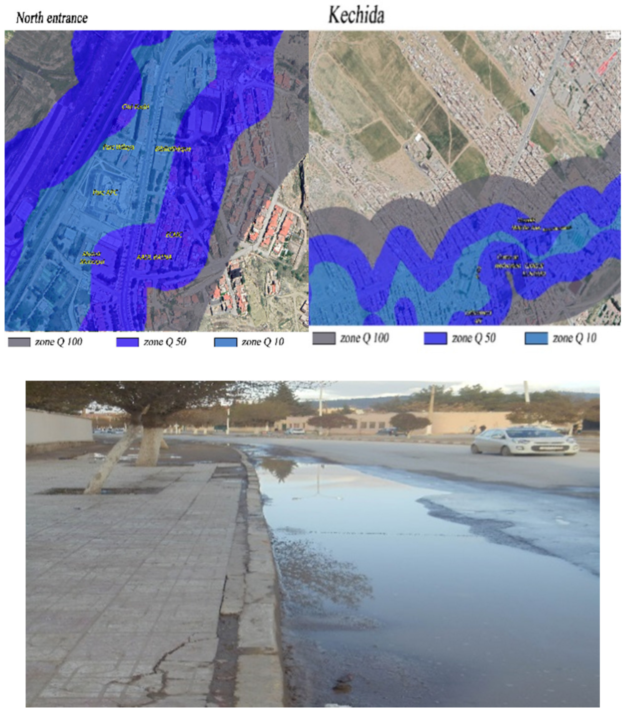


Fig. 23. Areas exposed to the risk of flooding at the north entrance of the city of Batna

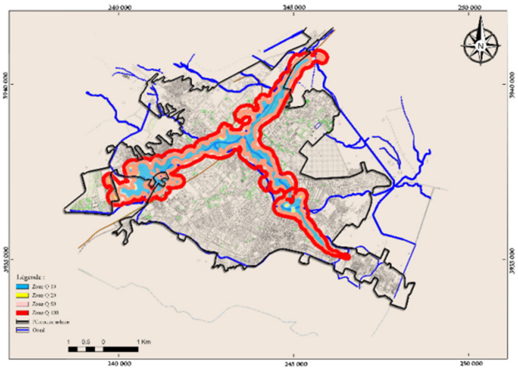


Fig. 24. Flood area mapping of Oued Batna and Oued El Gourzi valleys based on 100-year frequency flow – under ArcGIS 10.3

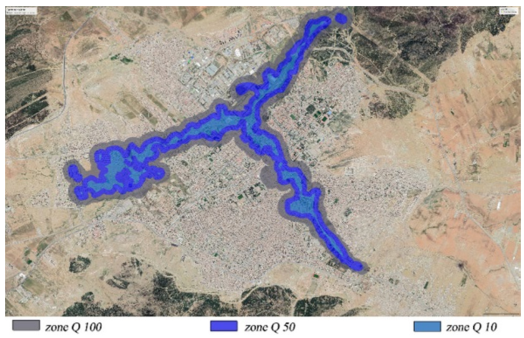


Fig. 25. Satellite image of flood areas related to the valleys Oued Batna and Oued El Gourzi using Google Earth Pro (Screenshot from Google Earth, Image © 2019 Maxar Technologies CNES/Airbus)

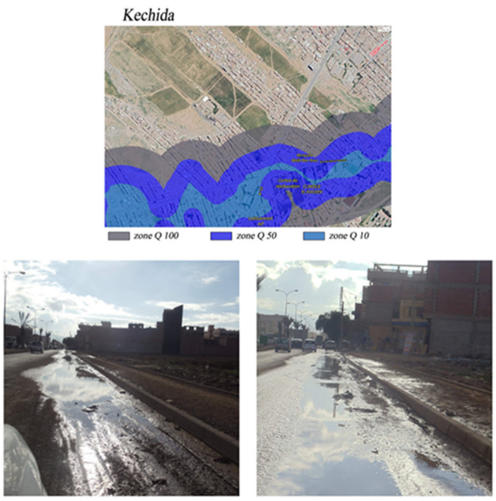


Fig. 26. Areas exposed to flooding risk at the level of Kechida Road

Fig. 27. Areas exposed to flooding risk at the University Hospital - Tazoult Road

Fig. 28. Areas exposed exposed to flooding risk in Zmalla and Verdure

V. CONCLUSION

The current paper has attempted to present a model for flood hazard mapping called HEC RAS-DTM. The presented model is based on mapping and simulation tools. The model has proved efficient in delineating flood hazard in the city of Batna in Algeria. The definitive delineated hazard thematic maps clearly illustrate that a significant portion of the city of Batna remains vulnerable to floods at varying degrees depending on the flood return periods predicted by the modeling. The mapping of the flood hazard designates that the flood locality is growing. This conclusion is drawn by analyzing the 10-year to 100-year floods of the valleys of Oued Batna and Oued El Gourzi and their crossing of the city.

It is suggested that the decision-makers of the city of Batna should take appropriate plans to alleviate the flood hazard. Flood hazard alleviation techniques could include raising the awareness of the locals of the omnipresent risk, the vegetation of the flood hazard area, construction of dams, and the introduction of evacuation simulation trainings at the level of civil protection units. The originality of the proposed methodology is based on the fact that it uses formulas adapted to the local context of Algerian cities, taking into consideration the specific geographical and climatic conditions of Algeria. The approach developed in this research uses widely available and easy accessible software such as HEC-RAS for hydraulic simulation and Arc-GIS for geographic data processing. The methodology is intended exclusively for local factors since the objective is to provide them with effective decision-making tools for flood risk management without waiting for the conclusions of experts in the event of a natural disaster.

However, the limitations of this methodology should be stressed. Some data, such as meteorological data, have been relatively easy to collect at the local level. However, updated satellite images were harder to collect. This constraint can be overcome by generalizing periodic technical training for local technicians in the field of GIS which does not require a lot of technological support. In this sense, it is assumed that the approach introduced in this paper is favorable in terms of being easily applicable to any Algerian city. It is useful because it allows, based on simple data collection, to objectively delineate the perimeter of parts of the city which would be submersible in the event of a sudden flood. The paper has demonstrated that the present approach, which is not very data-intensive, could easily substitute the conventional methods based on risk maps, often based on in situ surveys. Future studies of flood mapping are advised to replicate the study in a different context using the suggested model in the current paper.

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