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Flood Inundation Mapping of Risk Zones in the Future Flood Events in Alfet River – Oued Al Abid Watershed – Using GIS Techniques and HEC-RAS Model

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Abstract

Despite the semi-arid to arid nature of its climate, Morocco is exposed, like all the Mediterranean countries, to floods which can be very damaging for public and private infrastructure and cause many victims. On Monday, August 10, 2015, following heavy rains, the water level of the Alfet river increase in a very remarkable way, causing severe flood which went through the village of Iminwargue (Azilal province). This flood has caused human life loses (5 deaths) and very serious material damage, including the destruction of 5 houses, and the collapse of two bridges over the Assif Ahansal river. This catastrophic event, led us to carry out a thorough study of the river Alfet watershed in order to establish a better understanding of its hydrological characteristics and how the inhabitants should react especially during intense rain periods. In this context, relying on a flow database and / or precipitation, a hydraulic simulation using the Hec-ras software was conducted to determine the extensive flooding in recurrences of 10, 50 and 100 years. The determination of flood levels help us to identify areas with a high risk to be affected for one century flood recurrence, and thereafter estimate the impacts in Iminwargue village.

Keywords: Alfet River, Flood inundation, GIS, Hec-ras, Hydraulic Modeling, Iminwargue.

Introduction

A flood can be defined as a mass of water, which produces runoff on land that is not normally covered by water or alternatively a flood is a fairly high flow, which overburdens the natural channel, provided for the runoff [1]. Floods are among the most devastating natural disasters in the world, claiming more than 20,000 lives per year and adversely affecting about 75 million people world-wide, mostly through homelessness [2].

Projected future climate change and associated extreme weather events like strong rainfalls are expected to even worsen the actual situation [3]. As the severity and frequency of flood events will considerably increase, the human societies realized that the traditional paradigm which enable to protect themselves against flood-related problems, such as embankments, channel straightening or detention basins implemented on a large scale to avoid the flooding of adjacent human-dominated areas and to protect the livelihoods of the residents [4-5] are not a sufficient option for the future [6]. Instead, the practitioners agree the flood management should be based on an integrated risk management approach [7] which it can help in decreasing flood related fatalities and associated economic losses.

Identifying prone areas can therefore be one of the key solutions in flood mitigation [8]. Predicting susceptible floodplains and high potential flash flood prone areas can help authorities in planning management strategies for flood mitigation such as designing water control structures (reservoir levee projects), decision making for flood insurance and facilitating emergency preparedness to cope with flooding [9-10].

Hydro-meteorological catastrophes cannot be totally evaded, but the impacts and after effects can be handled by developing effective risk reduction strategies through the application of latest geospatial tools and decision support systems [11]. The application of full modeling steps from rainfall-runoff to damage modeling is a paramount necessity tool to gain spatial coherence when estimating losses [12-13]. Hydraulic modeling simulates the effects of flood in actual existent defense measures [13-14] considering all the probabilities of protection measure failure as well [15-16]. Then comparison and evaluation of the effects of the protection measures on flooding events are done in a risk-based context [17].

To identify flood prone areas, a model is required to predict a spatially distributed estimate of the hydraulic variables such as flood inundation extent and depth. 1D and 2D dimensional hydraulic models are now widely used for this purpose. These models are able to compute water surface profiles rapidly in several different characterizations of the system [18].

A geographic information system (GIS) is an appropriate tool that can be used in the different scientific fields such as hydrodynamics, flood zoning maps… With its unique visual display capabilities and database management tools, the GIS allow linkage of the hydraulic data to spatial location [19] which can be considerate as a fit and lawful tool for determination and planning of emergency strategies, by understanding the extent of flooding, and allowing to decision makers to decide about how to best allocate resources in order to prepare for future emergencies [11].

The main advantage of using GIS for water court analysis is that it creates potential analysis events for more estimating the damages due to flooding. Almost the majority of studies have applied hydrologic and hydraulic models (whether it is one-dimensional or two-dimensional) to simulate the flood in a specific study area and give information about the risk assessment and the likelihood of flood occurrence [20–23]. Incorporating hydraulic data with spatial data into a GIS environment has proven to be highly effective with regards to 2-D and 3-D floodplain visualization [24]. The Hec-ras software (Hydrological Engineering Centre System for Analysis of the River) is among others software of one-dimensional modeling (two-dimensional has the latest software), is well suited for development of inundation maps in a variety of applications like GIS and have been used by several researchers such as in 2005, by Goel [25] that he present the art for the preparation of the flood risk maps that include the development of DEM (Digital Elevation Model) and simulation of flood discharges for different return periods. And in 2002 Shamsi [24] integrated GIS Technology in Hec-ras for scientifically quantified information effective in the simulation, and the identification and analysis of flood events in a geo-spatial environment, which helps viewing flood simulations, and also shows the spatial impact of different scenarios with the most vulnerable areas to flooding. According to Orok 2011 [26] he said that the use of software of flood risk maps should be able to identify the most vulnerable areas to flooding and estimate the number of people who will be affected by future floods in a well specified area. And according to Hassanpour in 2012 [27], The results of flood maps provide valuable information for managers and experts to minimize flood damage. Based on literature reviews, implementing similar approaches to flood management and monitoring systems can possibly help mitigate the flooding risks. Today forecasting systems have a significant impact in reducing losses. Using these technologies advances, we can improve the design of flood mitigation, and provide earlier and issue possible warnings to people living in low areas that fend to be affected.

Purpose and Need

In Morocco, the frequency and intensity of floods in recent decades have grown in a very remarkable way, especially in the basin of the Oued Al Abid, due to the heavy intensity of rain and rugged topography characterize by high slope. In the study area, rainfall is very intense during the summer storms. That rainfall is a very important weather factor because its excessive quantity is likely to coincide with the peak flow in the upper river basin, which can increase the probability of violent flood formation. The highest recorded flood recorded in the Alfet river was on August 10th 2015 when the water level raises by 10m above the river bed and causes the death of 5 peoples, the destruction of 5 houses and the road N°302 linking the two centers Tillouguite and Aminouak. This event was the most deadly catastrophe that Iminwargue village had ever experienced in its history according to the local authority. The following photos (Figure 1) show some damages from the disaster last seen in the study area.

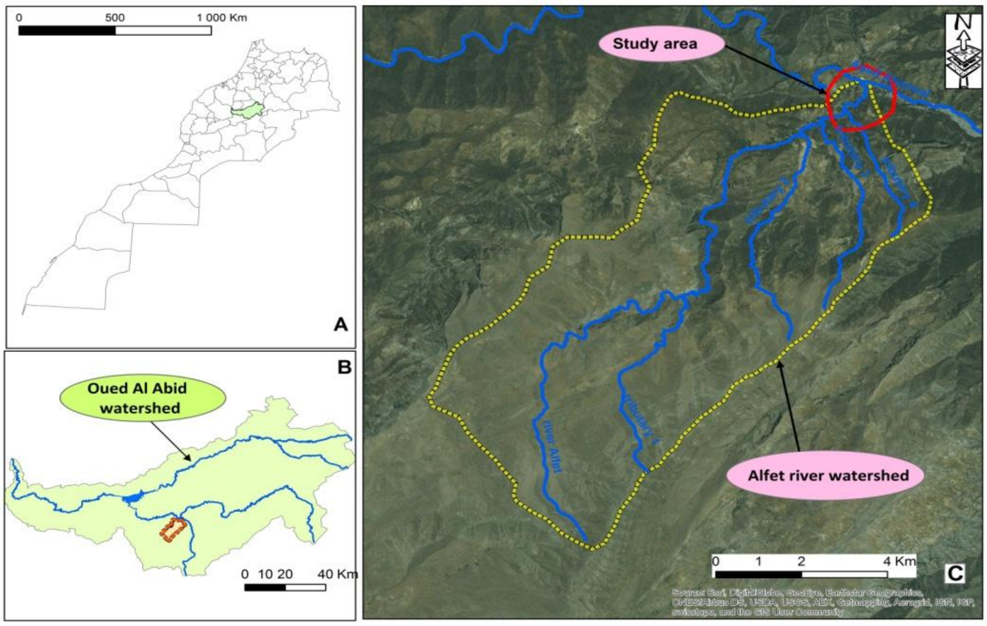
Figure 1. ***(A)*** *Traces of a Destroyed House* ***(B)*** *The Flood Lines on the Inside of a House*

The Study Area

Administratively, Iminwargue village is a part of the region of Khenifra-Beni Mellal, and Azilal province, municipality of Tillouguite. The basin of Iminwargue is located in the sequent geographical coordinates: longitude from 6°15’57’’ to 6°08’22’’West and latitude from 32°00’03’’ to 31°53’04’’ West (Figure 2). The sub watershed of Alfet River is a part of Oued Al Abid watershed. It rises at an altitude of 2527 m in the High Atlas of Morocco, in a distance of 30 km from the Azilal town.

The climate in the region of Iminwargue is semi-arid, characterized by a concentration of rainfall in autumn and winter. This climate is characterized by high evaporation and high average temperatures with high monthly and daily amplitude. Winter is usually cold, while summer is hot and dry. The average minimum temperature is about 18.3 °C in August to 5 °C in January. The average maximum temperature ranges from 34.9 ° C in August to 15.8 °C in January.

Figure 2. *Location of the Study Area*

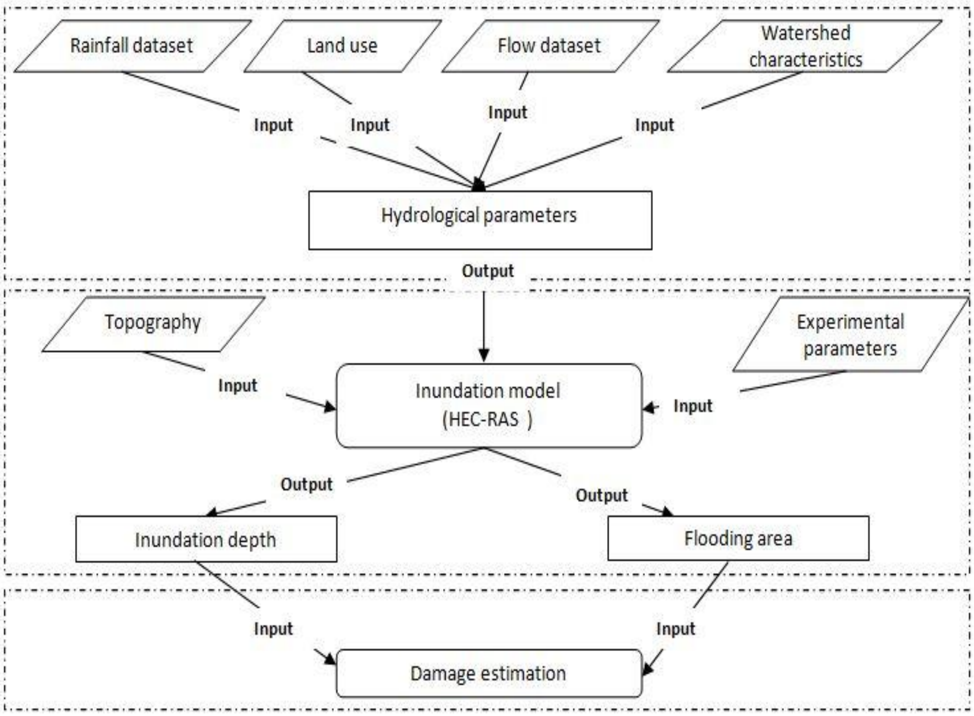


Materials and Methodology

The first step in the methodology starts with the collection process of data from different sources. In our case, we require a spatial and hydrological data, channel geometry, boundary conditions and channel resistance. These data are necessary for conducting flow simulation through the Hec-ras model. The topographic maps and some statistics about the damages of the last inundations were given by the Authority of Tillouguite. The hydrological and climatic data have been provided from the Meteorological Department in the hydrological basin agency of Oum Er-Rbia in Beni Mellal city.

The proposed methodology (Figure 3) consists of three major parts: the first part is a hydrological study, which allows to determinate the recurrence flow and precipitations in different time. The second part is a hydraulic simulation using Hec-ras to indicate the extension of the flooding event. And the last step is to estimate the damage caused by the inundation events.

Figure 3. *The Methodology of Work*



Hydrological Study

The majority of studies carried out to identify floodplain inundation areas have been done at gauged rivers or have been done based on available flow information of upstream station(s), The lack of data for ungauged rivers such as the Alfet river often deprives researchers to get an accurate prediction of flood magnitude as a key factor for a reliable flood inundation mapping [2].

Flood magnitude prediction at ungauged stations is an important task in designing river engineering and hydraulic structures and remains a fundamental challenge for hydrologists [28]. At ungauged basins, hydrological regionalization is usually applied as a reliable method for the estimation of the hydro-climatic variables at different return periods in the site of interest [29].

Physiographic features of watershed are very important elements in the knowledge of the hydrological response of rivers to be delimited. These parameters are calculated on the basis of the delimitation made, and are summarized in Table 1 below.

Table 1. *General Characteristics of the Alfet River Watershed*

General parameters	Alfet river	General parameters	Alfet river
Area (Km²)	66.81	Difference in height (m)	1404
Perimeter (Km)	39.29	Slope (%)	6.77
Length (Km)	20.73	Equiv length (Km)	15.48
Max elevation	2527	Equiv length (Km)	4.32
Min elevation	1123	IC Gravelius	1.36
X, Y outlet (m)	306 786 147 382	Concentration time Tc (min)	274.37

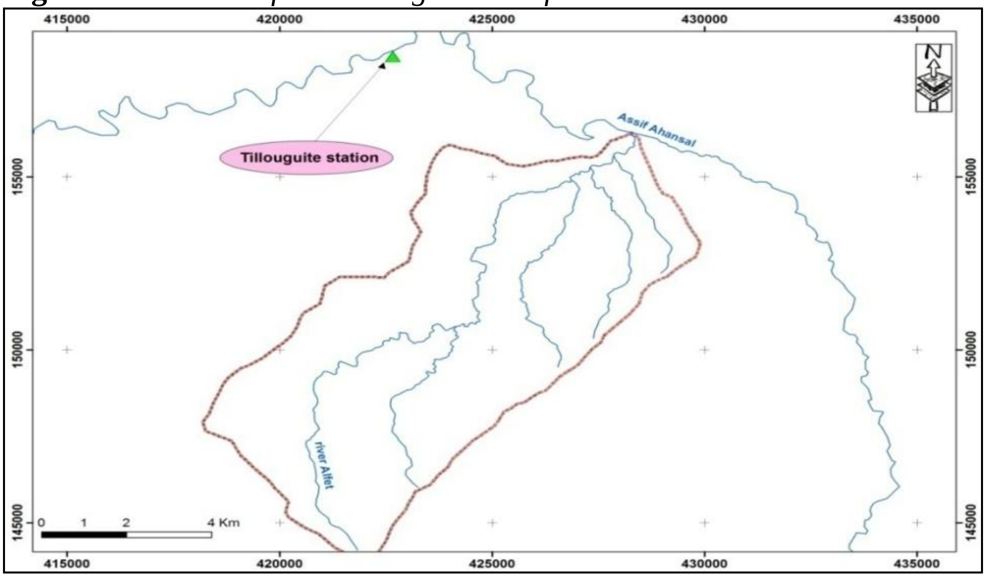
Precipitation Adjustment

The precipitation data adopted in our study are those of the Tillouguite station, located 3 km from the north east of the watershed. The information and location of Tillouguite station are summarized in the following table (Table 2) and map (Figure 4):

Table 2. *Description of the Rainfall Station Used "Tillouguite Station"*

Station Name	N° IRE	Coordinates			Measuring period
		X	Y	Z	
Tillouguite	138/46	422 674	158 474	1100	1977-2011

Figure 4. *Location of the Tillouguite Rainfall Station*



The rainfall statistical adjustment was carried out through the statistical analysis software HYfran which have been used by several researchers [30-31] to determinate the predicted precipitation in different returns periods and allows:

- Checking assumptions: independence, homogeneity
- Adjusting to 16 laws (exponential, GEV, Gumbel, normal, lognormal, Weibull, gamma ...)
- Determining the quintile with confidence intervals
- Choosing the most appropriate category distributions to estimate the high return period quintile.

The results obtained by the different adjustment laws are summarized in the following table (Table 3):

Table 3. *Comparison Criteria of the Distributions Obtained by HYfran*

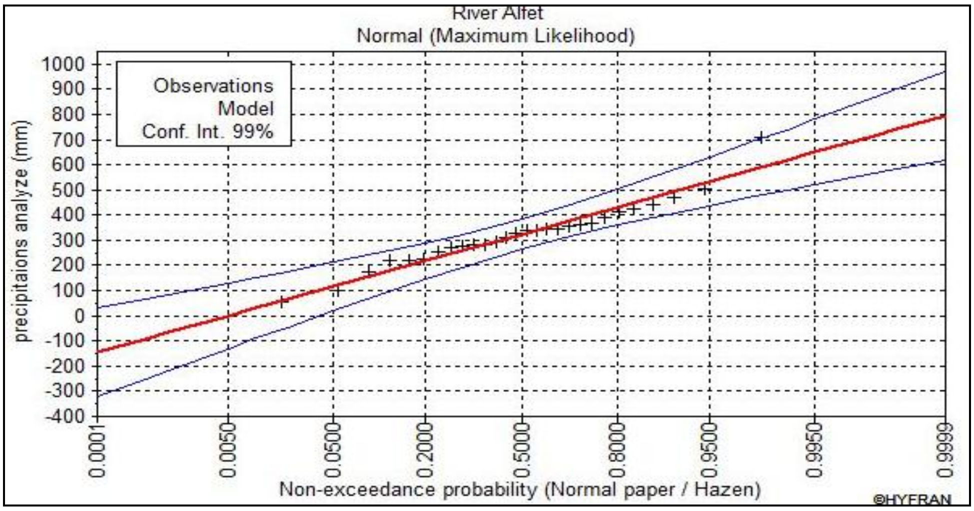
Model	Nb param	XT	P(Mi)	P(Mi|x)	BIC	AIC
Normal (Maximum likelihood)	2	619.14	12.50	39.35	356.17	353.51
Weibull (Maximum likelihood)	2	636.25	12.50	34.19	356.45	353.79
Pearson type 3(Maximum likelihood)	3	638.22	12.50	10.95	358.73	354.73
Gamma (Method of moments)	2	688.73	12.50	10.33	358.85	356.18
Gumbel (Method of moments)	2	721.58	12.50	4.20	360.65	357.98
Lognormal (Maximum likelihood)	2	920.79	12.50	0.97	363.58	360.91
Inverse Gamma (Maximum likelihood)	2	1449.74	12.50	0.01	372.72	370.06
Exponential (Maximum likelihood)	2	1326.10	12.50	0.00	377.75	375.09

The choice of the law that fits best must meet the following criteria [32]:

- The lowest AIC and BIC coefficients
- The greatest posterior probability

In our case, the adjustment of the precipitation by the software HYfran showed that the Normal distribution law fits the best to our meteorological data. To confirm our choice, the following graph (Figure 5) represents the distribution of precipitation measurements according to a normal distribution in a confidence interval of 99%, and exhibits that almost all data are represented in the interval of confidence selected.

Figure 5. *The Graphic Representation of Monthly Rainfall as the Normal Distribution*



The results obtained by the adjustment to the normal distribution are given in the following (Table 4):

Table 4. *The Statistical Adjustment Results of Precipitation by the Normal Distribution*

T	q	XT	Standard	Confidence interval
100	0.9900	619.14	46.644	498.97- 739.30
50	0.9800	584.66	42.682	474.70- 694.62
20	0.950	532.93	37.060	437.45- 628.40
10	0.9000	486.95	32.530	403.14- 570.75
5	0.8000	431.26	27.951	359.25- 503.26
2	0.5000	324.82	23.905	263.23- 386.40

Calculation of Flow

This part of the study aims to estimate the peak flow rates for different frequencies. This calculation for ungauged stations presents a challenge to hydrologists due to the use of statistical concepts, deterministic and regionalization formulas. To carry out these calculations and based on some researchers work, the following approaches can be adopted [33]:

- Empirical approach: If there is no rainfall or hydrometric data or if the duration of observation and recording is insufficient then the flow peak assessment is based on the geometric parameters of each watercourse as the physical characteristics (length of the river, average slope, vegetation cover, rainfall annual) by the use of formulas such as Mallet-Gauthier, Hazan Lazarevic, Fuller II…
- Hydro meteorological approach: a method based on rainfall information to calculate the flow peak.

Based on the two approaches, we have calculated the flow through the various formulas and we found the following results (Table 5):

Table 5. *The Results of the Flow according to Different Recurrences Times*

Flow point m3/s (Alfet River)						
Recurrences time	Q(02)	Q(05)	Q(10)	Q(20)	Q(50)	Q(100)
Alfet river	72.84	96.46	112.05	116.46	143.51	166.72

Hydraulic Study

The objective of this part is to project the calculated flow in different sections of the Alfet River in order to know the extent of flood areas and to assess the risk of overflow at the neighboring rivers surfaces.

The simulations were performed to define the highest water levels related to the spread of floods in different occurrence periods (2, 5, 10, 20, 50 and 100 years), and their speed and other characteristics.

The hydraulic simulation, in one-dimensional (1D) software, required a number of data including topographic data in the form of a series of cross-sections, a friction parameter in the form of Manning's n values across each cross-section, flow rates, flow change locations, and boundary conditions.

The one-dimensional (1D) software, such as Mike 11, ISIS or Hec-ras, are based on the water Equations or variations, and still form the majority of traditional numerical hydraulic models used in practical river engineering. in practice might be explained not only by the fact that 1D models are (in comparison to higher dimensional models) simple to use and require a minimal amount of input data and computer power, but also because the basic concepts and programs have already been around for several decades [34].

In this study we choose to use the software package of Hydrologic Engineering Center's River Analysis System (Hec-ras). This model can be used for both steady and unsteady flow, and sub and supercritical flow regimes. With its companion utility, Hec-GeoRas and ArcView©, integration with GIS makes both the construction of the model geometry and the post-processing of the output in an easy manner [35].

Except geometry, all other data including flow data, boundary conditions, information on structures (bridge/culvert/levees) and land use (to get Manning's n) that are extracted from Hec-ras base models remain unchanged for the simulations process [36].

<u>Topographic Datasets</u>

The Channel geometry, channel resistance and boundary conditions are required for conducting flow simulation through Hec-ras [37]. The municipality of Tillouguite has provided the geometric data that covers the urbanized part of the Iminwargue center in a total surface of 2.1 km2 as a contour map in Auto CAD (.dwg file) format. A total of 31 cross-sections at various important locations on the river have been used.

Simulation Results

The simulation in Hec-ras has allowed to get multiple results such as the water elevation, the type of flow (torrentially or fluvial), and speed of flow in each section, all these results are summarized in Hec-ras Table 6 below.

Table 6. *Extract from the Table of Hec-ras Results*

Profil	Year of return	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Water Elev (m)	Water Speed (m/s)	Flow Area (m2)	Top Width (m)	Froude chl
1	100year	166.72	1181.7	1183.66	1.96	3.34	49.92	44.35	1
2	100year	166.72	1179.99	1181.21	1.22	5.72	29.15	44.1	2.25
3	100year	166.72	1179.18	1180.68	1.5	3.94	42.35	53.02	1.41
4	100year	166.72	1176.11	1177.15	1.04	6.69	24.93	43.9	2.83

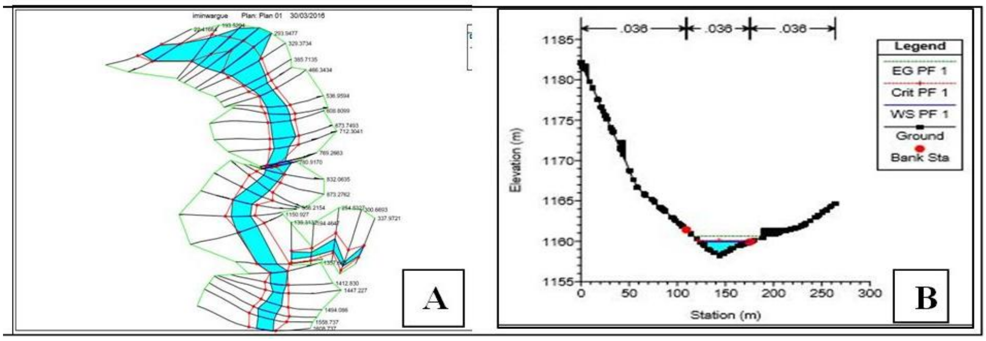
Q-total: total discharge, **Min Ch El**: min channel elevation (is elevation of each station, **W.S Elev**: Elevation of water surface, **Water Elev**: water elevation, **Flow Area**: Area that flood covers, **Top Width**: Maximum of elevation of flood surface, **Froude Chl**: Froude number that can be critical, sub-critical of hyper-critical.

The results obtained from the Hec-ras table above can be recapitulated as follows:

- The flow regime is usually torrential, characterized by Froude numbers greater than unity (Fr > 1) in 78.1% of the simulated sections. the remaining sections present Froude numbers that are lower in unit (Fr < 1);
- The average speed related to the centennial flood varies between 0.36 m/s (V min) and 6.69 m/s (Vmax) while the average velocity (V mean) is 3.53 m/s.

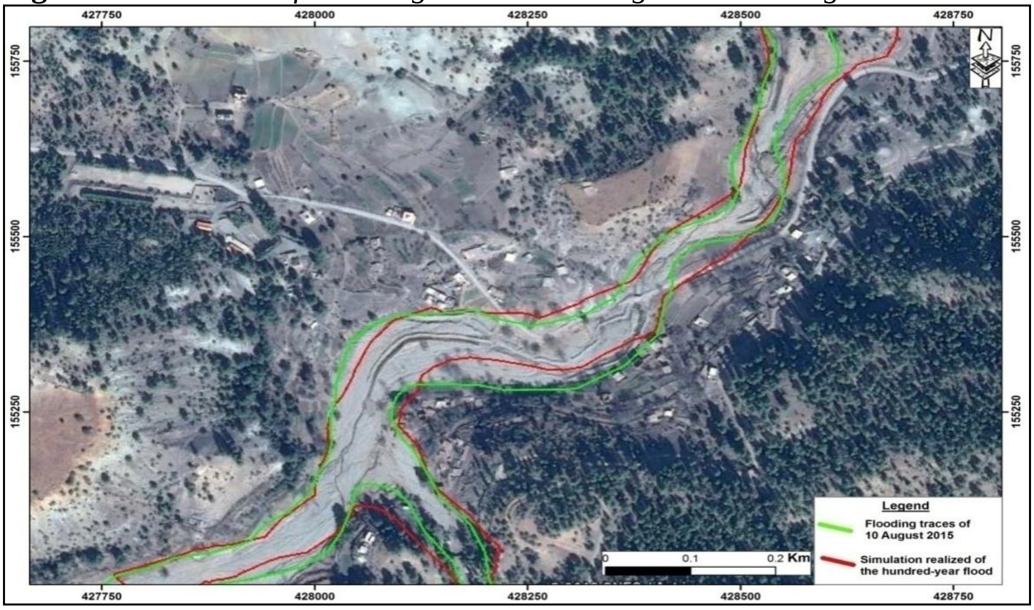
Hec-ras also allows visualizing 3D and 2D representations of the flood along the river course. Figure 6 gives an example of these results:

Figure 6. ***(A)*** *Schema 3D of Flooding Zones* ***(B)*** *The Water Level in a Cross Section*



The limits of flooding zones outcome from the hydraulic simulation of the hundred-year flood are represented in the background of a Google Earth image (Figure 7) to show the extent of the simulated flood on the actual situation.

Figure 7. *The Limits of Flooding Zones in a Google Earth Background*



Discussion

Hydraulics simulation for floodplain mapping is a good management and engineering tool, it can be applied to prevent unwise land use in flood prone areas, and the design of bridge and culvert opening for roadway, the streams reduction measures such as the dams [38].

According to several research studies carried out in the flood protection section, validation remains still very difficult to complete and achieve [39] to bring out some researchers are generally based on the historical floods recorded in the study area (Same pace or power) to compare and validate the results of the simulated flood zones. This means that the hydraulic modeling gives very exploitable results in terms of delimitation of the flood zones but remain with a margin of error extremely small view that no one can validate them surely, [40] this margin can be neglected in The majority of the cases, because this constraint can be avoided by adding an additional distance on the boundaries of the flood zones to avoid any repercussion or error of the Hec-ras model. In our case study we use the limits reached by the flood of August 15, 2015 as much it's the most destructive event that happened in the study area, and the traces are always apparent, so, we carried out a comparison of the quantity of precipitation and flow record in the station near to Iminwargue center and we found that they are almost nearby close.

Using an aerial photo (Recent Google maps) as a base map, the impacts of selected flood recurrence period, on both river and nearby structures, can be quickly assessed. Figure 7 shows an example of how the resulting flood map can be used for emergency prediction in flood events. The 100-year floodplain modeling result provides rich information concerning the flood extent and depth at the building of interest. As a result it can be seen that the

100 year flood will touch the sets of buildings on the right bank which are in numbers of seven, and the school that is located near the right bank of the road, and will invade almost the entire road that through the center and contain an hydraulic structure an double box culverts due to its insufficient capacity to spill out the quantity of flood flow.

As has already been mentioned, the margin of error which may affect the results of the hydraulic simulation may be linked to the flow will come out of bank earlier and the water elevation surface in the overbanks will be slightly lower than in reality. That error is due to the one dimensionality of Hec-ras that generalize the same conditions in the totality of the river. But despite all, the results are usable and generally accepted for use in planning and design, because those errors are inconsequential for the analysis at the watershed level.

Conclusions

This research deals with integrating the hydraulic data with GIS to map the desired inundated floodplain zones. As results, the hydraulic modeling using GIS and Hec-ras techniques prove that they are very useful for this kind of phenomenon and give satisfactory results that can be a tool for governors to make the decisions. As we noticed the GIS helped to visualize different scenarios and mapping of the high risk areas. And the software Hec-ras model was used to simulate floods in different return periods for the Alfet river basin. This coupling predicted flood extents of approximately 127 square meters for the return period of 100 years and a maximum rise of the Alfet river level in about 5.03m, and these results show that the population located near to the banks, agricultural land and other useful infrastructure such as roads and bridges are in very high floods risk.

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