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Floods Simulation for Arid City Using GIS and HEC RAS: Case of M'chouneche South-East of Algeria

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Abstract

The study of floods is a topic of increasing interest in the field of risk management because it constitutes the most recurring natural disaster in the world that causes significant damage. Algeria is among the Mediterranean countries that are affected by sudden and unpredictable floods. According to the Algerian civil protection services, one out of three municipalities is likely to be flooded, in part or in full. In recent decades, extreme hydrological events have occurred in the arid city of M'chouneche. Their high frequency and dependence on climate change, in addition to the increasing demographic pressure on the shores of valleys, make them a cause for concern and difficult to manage. The use of empirical, hydrodynamic, or conceptual models and geographical information systems (GIS) has become a valuable approach for assessing natural hazards, especially floods.

This work aims to simulate floods for a 10-year and 100-year return periods with a one-dimensional (1-D) model using HEC RAS (Hydrologic Engineering Centers River Analysis System) software, GIS (Geographic Information System), and remote sensing (RS). The result is a decision support tool for local authorities based on feedback experience from extreme hydrological events and flood frequency analysis for different return periods to identify probable flood scenarios and provide valuable decision support for emergency response and crisis management.

Key words: Arid city, climate change, decision support tool, floods, GIS.

INTRODUCTION

Floods are among the most frequent types of natural risks, causing significant damage throughout the world. Algeria is among the Mediterranean countries that are affected by floods whose appearance is sudden and often unpredictable. The determination of vulnerability reflects the degree of loss inflicted on the exposed elements by the occurrence of a flood. It is primarily a question of measuring land use via the current urban planning documents to determine where land control is necessary. It was established on the basis of several attempts to assess vulnerability in the urban environment (Kazmierczak, Cavani, 2011) and generally based on residential density in the urban environment. The study of floods is a topic of increasing interest in the field of natural hazards management because, over more than 50 years of observations, extreme hydrological events have occurred in the area under study. They are generally associated with intense rainfall events and occur in moderately sized ponds. Arid and semi-arid regions, covering a large fraction of the global land area (Zeng et al. 2008), are affected by high-impact flooding. Our study focuses on medium- and long term floodplain inundation using GIS and HEC RAS. In the current study, simulations of 10-year and 100-year return periods are done along the M'chouneche valley, located south-east of Algeria. On the one hand, it constitutes a vulnerable ecosystem for flooding, which hinders the development of this region. In addition, it has experienced extreme hydrological events in recent decades related to climate change and demographic pressure, which makes them a cause for concern. According to the Algerian civil protection services, 33% of the Algerian municipalities are likely to be flooded, in part or in full. A list of commonly used models can be found at FEMA (2014). In previous years, the most effective models were physical and small-scale. Currently, they have become more efficient thanks to the simulations they offer. However, some hydraulic models are very difficult to achieve due to the complexity of calculating some parameters and the data requirements. The choice of a hydraulic model depends on various criteria like the quality of the input data (DEM), land use, maximum flow discharge, water depth, velocity, watershed characteristics, and scale. Models can be presented in many categories: empirical, hydrodynamic, conceptual, 1-D, 2-D, and 3-D, according to their spatial dimension (Mancini M., 2008; Ravazzani et al., 2008; Randa O. Tom et al., 2022). When covering an area larger than

1000 square kilometers, 3-D hydrodynamic models are generally deemed unviable, especially when a high-resolution simulation is required. Shuttle radar topography mission (SRTM) DEM 30x30m data combined with Sentinel synthetic aperture radar data is used in the GIS platform to prepare flood hazard layers based on the probability of flood inundation (George SL, Kantamaneni K, et al., 2022). Accurate and reliable simulation using HEC-RAS can prove an effective method for developing flood forecasting and warning systems (Loi NK, et al. 2019). Due to climatic variability in time and space, the use of simulation models has become a very common tool for assessing and managing natural hazards, including floods. Geographic Information System (GIS) is a powerful and useful tool that allows for the spatial analysis of hydraulic modeling results, such as those from the HEC-RAS/HEC-Geo-RAS software (Leal M., Reis E., Santos PP., 2022).The most appropriate model based on the needs of the risk assessment and the available data is the one-dimensional (1-D) model. It is a simplified model that characterizes the terrain properties using a series of cross-sections. For each cross-section, the depth and velocity of the flow perpendicular to the cross-section are calculated. The one-dimensional model can be run in two different ways, depending on the nature of the input design discharge.

DATA AND METHODS

The 1-D model integrated into GIS is a reliable approach for floods simulation. It constitutes a valuable tool for flood hazard assessment, management, and decision-making. The input data required are the geometry of the valley reach, the cross-sections that are perpendicular to the predominant flow direction and that incorporate valley channel and floodplain geometry, the topography resulting from the DEM, the network of drains (flowpaths), and the land use. After digitizing all the data and viewing the model, it is imported into Arc GIS, where the different layers are extracted using the functionality of HEC GeoRas. Frequency analysis is a statistical method of prediction consisting of studying past events, characteristic of a hydrological process, in order to define the probabilities of their future occurrence. Flood frequency is calculated on the basis of the maximum flood discharge recorded at the Foum El Gherza dam gauging station from 1950 to 2020. Recall that the maximum flows have been adjusted with different statistical distribution functions, of which the GEV (generalized extreme values) seems most appropriate for the selected sample. The objective of this component is to develop a floodplain simulation for medium- and long-term floods with the hydraulic one-dimensional model. The principle is floods mapping for 10-year and 100-year return periods according to the maximum flow discharges recorded by the National Agency for Dams and Transfers (NADT) using GIS and HEC-RAS software.

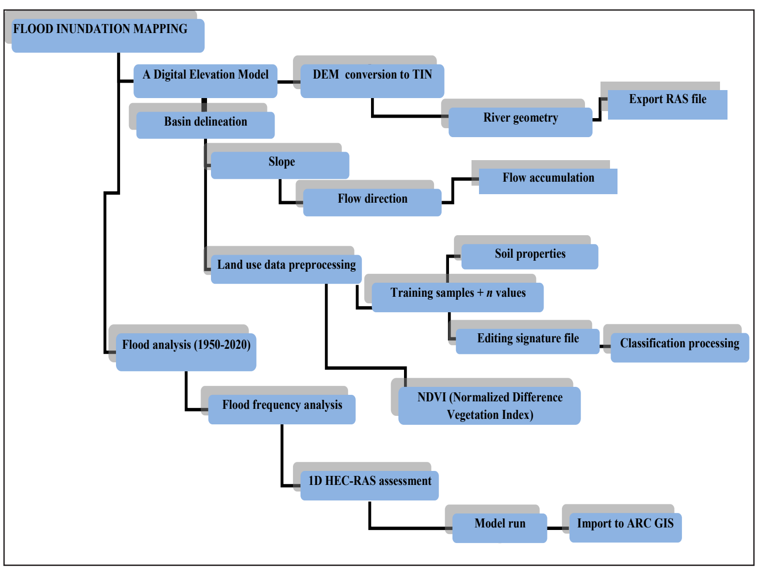

Figure 1. Flowshart of methodology

The HEC Geo-RAS extension, which can be used on Arc GIS for geospatial data, makes the Hydrologic Engineering Center's River Analysis System extremely useful. The basis of calculation for unsteady flow mode is based on the resolution of the dynamic set of Adhémar Jean-Claude Barré de Saint-Venant (1848) equations, based on Navier-Stokes equations by the method of finite differences:

$$B \frac{\partial V}{\partial t} + \frac{\partial (A V)}{dx} - q = 0 \qquad (1)$$

$$\frac{1}{g}\frac{\partial V}{\partial t}+\frac{V}{g}\frac{\partial V}{\partial x}+\frac{\partial y}{\partial x}+if-i0+\frac{q}{gA}(v-Ux)=0 \qquad (2)$$

(1) describes mass conservation and (2) Newton's dynamic motion where:

t : is the time; x : x-axis along the channel; y : flow depth; **v**: the flow velocity, A , B : the cross-section area and width respectively; g : acceleration of gravity; q : lateral inflow per unit length; Ux : velocity of the lateral incoming flow in the x-direction; if : slope of the energy line; $i0$ = slope of the bottom of the canal.

In the present work, 1D model is run in unsteady mode, in which discharge rates and water levels across the City of M'chouneche can vary over time based on a complete hydrograph of flow discharge recorded by NADT.

The Study Area

The city under study is located 28 km north of Biskra province (southern Algeria). It extends over more than 504 km², and its population is about 10,000. The city of M'chouneche is characterized by an arid climate with a cold winter and a hot, dry summer.

It is about 450 km south-east of Algiers between 34° 55' 70" and 34° 58' N latitude and 5° 59' and 6° 01' E longitude as shown in figure 02. It constitutes a region of plains and desert landscapes and the dominant sector is agriculture, particularly cereal crops, fruit trees, and a large portion of date palms.

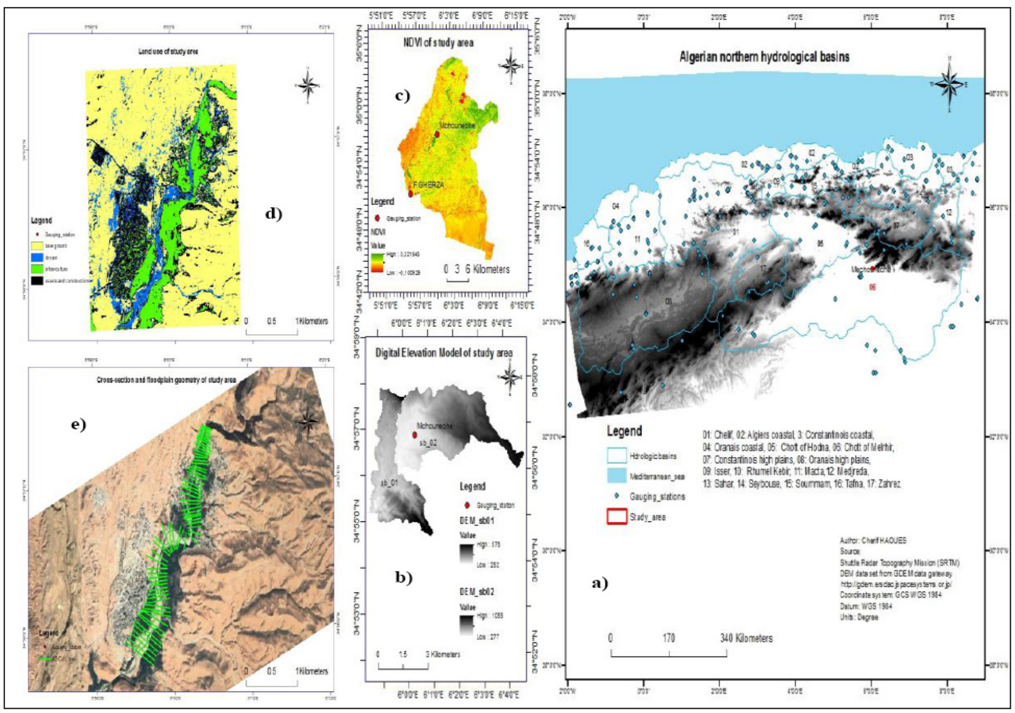

Figure 2. Study area: a) Location, b) DEM, c) NDVI, d) Land use, e) Cross-section geometry

Due to its size, topography, and socio-economic challenges, it constitutes a vulnerable ecosystem for flooding, which hinders the development of this city. The city of M'Chouneche is fed by the White Valley, which routes to M'Chouneche Valley, crossing the Chenaoura, Tighanimine, and Ghassira valleys. It is dominated by irregular rainfall resulting in seasonal flooding, particularly in autumn and spring. The studied city has experienced extreme hydrological events in recent decades (2011, 2016, and 2018), which are probably related to climate change and demographic pressure on the shores of valleys, which makes them a cause for concern.

RESULTS AND DISCUSSION

Analysis of feedback experience from extreme hydrological events between 1950 and 2020 shows that the study city recorded an average of 6 floods/year. At seasonal intervals, the floods are recorded in the autumn and spring (158 in the autumn and 119 in the spring), compared to 68 in the winter and 64 in the summer.

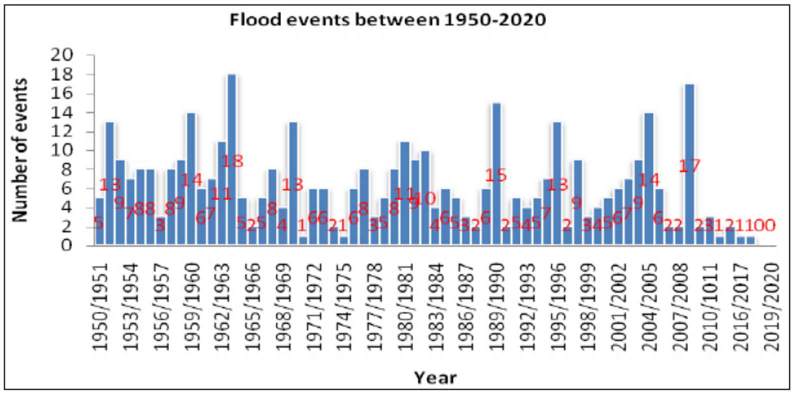

Figure 3. Flood events between 1950-2020

At monthly intervals, floods are more frequent in September, with 82 events, compared with 47 events in October, 42 in March and April. Flood frequency is calculated for 10-year and 100-year return periods on the basis of the maximum flood discharge recorded at Foum El Gherza dam gauging station between 1950 and 2020 using GEV distribution.

The perspective plot of floods for 10-year and 100-year return periods upstream and downstream of the main valley is shown below:

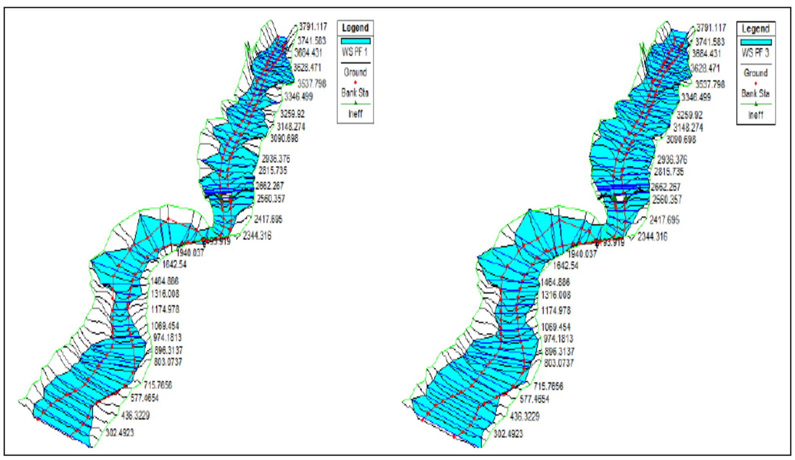

Figure 4. Perspective flood plot for 10-year and 100-year return periods

Flood frequency analysis for M'chouneche city shows that flood magnitudes vary between 1462.61 m^3/s and 3017.26 m^3/s for the 10-year and 100-year return periods, respectively.

Table 1. Flood response parameters for 10 and 100-year return periods

10-year return period			Response parameters	100-year return period		
Left Bank	**Channel**	**Right Bank**		**Left Bank**	**Channel**	**Right Bank**
0.025	0.075	0.025	Manning's Roughnes Coefficient *n*	0.025	0.075	0.025
30.63	251.47	02.98	Flow area (m^2)	167.71	520.12	72.71
284.50	1462.61	12.89	Flow (m^3/s)	1908.50	3017.26	664.24
09.29	05.82	04.32	Velocity (m/s)	11.38	07.35	09.14
02.04	05.00	0.63	Hydraulic D.(m)	04.72	10.35	03.28
370.58	370.58	370.58	W.S elevation (m)	375.93	375.93	375.93
15.50	51.15	04.89	Wetted perimeter (m)	36.67	51.15	23.14

Manning's roughness coefficient is increasing from 0.025 for the left and right banks to 0.075 for the main channel. The average velocity increases from 05.82 m/s to 07.35 m/s, while the water surface elevation (WSE) increases from 370.58 m to 375.93 m and the hydraulic depth increases from 05.00 m to 10.35 m.

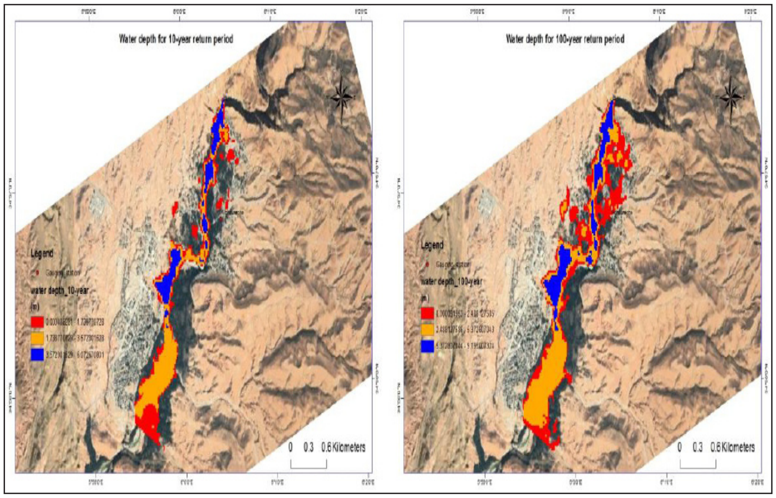

Figure 5. Water depth variation for 10-year and 100-year return periods

CONCLUSION

The integration of a one-dimensional hydraulic model into a geographic information system is a simple and reliable approach for flood simulation in developing countries.

The one-dimensional model, compared to other hydrological models, is much simpler and requires only some GIS skills. The 1-D model can be done using HEC RAS software, which has the ability to automatically solve the mathematical formulas presented above in this research. The 1-D model also has the advantage of using open-source software and data that allow developing countries to benefit from it to develop a relevant flood forecasting and warning system and simulate floods accurately. The one-dimensional model integrating GIS and HEC RAS was used in the city of M'chouneche located south-east of Algeria, and provides a major help for decision-makers and local authorities for urbanized area adaptation to climate change and flood management for different return periods. This decision-support tool contributes more to the economic and sustainable development of the studied city thanks to the information it provides.

The present work has resulted in the flood simulation for 10-year and 100-year return periods for both sides of the city. The current study demonstrated that a 1-D model can be profitably applied for arid environment, providing a useful decision-making tool to optimize flood risk management.

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