

Flood risk vulnerability assessment using GIS and hydraulic modeling, case study of the Fez river watershed, Morocco

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Abstract. Morocco, like other countries in the world, is threatened by floods. These have become frequent in previous years and the current year (2024). Weather-related floods in the Fez river watershed constitute the natural hazard that threatens property. In this work, we adopted an approach based on the modeling of flow processes using the HEC-RAS model. The main sources of information are topographic map, geological map, hydrometeorological data, digital terrain model (DTM), land use, etc. 2D and 3D hydraulic modeling using HEC-RAS software, allowed the mapping and analysis of floodplains. The HEC-RAS hydraulic modeling tool is used to perform permanent flow simulations and the model input files are developed in GIS software using the HEC-GeoRAS extension. The results of the study further indicate that the Geographic Information System combined with hydraulic modeling are very effective tools for floodplain mapping and analysis. The resulting map is the flood risk map. This useful information can be used to plan and control future floods and will thus help in sustainable land management.

Keywords: Fes, GIS, HEC-RAS, Hydraulic modelling, flood susceptibility

1. Introduction

Floods are the most common natural disasters that affect most of the world's population. In recent times, severe floods in urban areas are becoming more frequent due to uncontrolled urbanization and climate change, and they will continue to increase in the coming years [1, 2]. Morocco, like other countries, has experienced climate change, rain has become irregular and is characterized by rapid and violent downpours, several natural disasters have occurred

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in recent years. Some disasters can be recurrent such as floods. Some areas of the territory are then subject to hazards and risks affecting the population and the economy. Flooding represents a danger for the economy and the population of the regions. Indeed, the Atlas valleys such as the floods of Ourika river in Marrakech in 1995, of El Maleh river in 2002 in Mohammedia. Also, during excessively rainy years, as in the case of the years (2008, 2009, 2010), the plain of Gharb (Sidi Slimane, Sidi Yahya, Sidi Kacem, etc.) other cities including Meknes, Fez, Taza, Casablanca, El Mohamadia, El Hajeb, Tinghir in November 2014 etc. In 2018, several cities experienced flooding, including the cities of Meknes and Fez. In 2024, the Draa-Tafilalet region, and other regions in Morocco, suffered floods and floods, affecting the lives of the population; material damage (constructions, infrastructure, agricultural crops), but also loss of human life.

The main objective of this work is to understand the flood risk in the city of Fez, and specifically the agglomerations of Fez and their infrastructures, through hydraulic flood modeling. Several tools are used, namely the combined use of remote sensing and geographic information systems (GIS). It is then a question of evaluating and spatializing the flood risk in order to provide the necessary information to local stakeholder

2. Study area

The city of Fez is located in the northern half of Morocco between $4^{\circ}54'40''$ and $5^{\circ}04'00''$ west longitude, and $33^{\circ}59'00''$ and $34^{\circ}05'00''$ north latitude, at the eastern end of the Saïs basin which itself is part of the South Rif Furrow. It's limited to the north by the pre-Rif ridges, formed by two massifs: that of Jbel Zalagh which culminates at 900 m, and that of Jbel Tghat, which culminates at approximately 837 m; to the south by the Middle Atlas cause, to the east by the valley of the Sebou river, and to the west by the Meknes Plateau [3-5].

With an area of 907 km², the watershed of the Fez river is composed of three different topographical units. The Middle Atlas cause in the south corresponds to the highest zone.) It takes the form of stepped plateaus from the South (Immouzzar cause: 2020 m towards the North (Sefrou cause: 1400 m). The Saïis plain represents the lowest part of the watershed (400 to 700 m), with a gentle slope (0.1%) from south to north [6, 7].

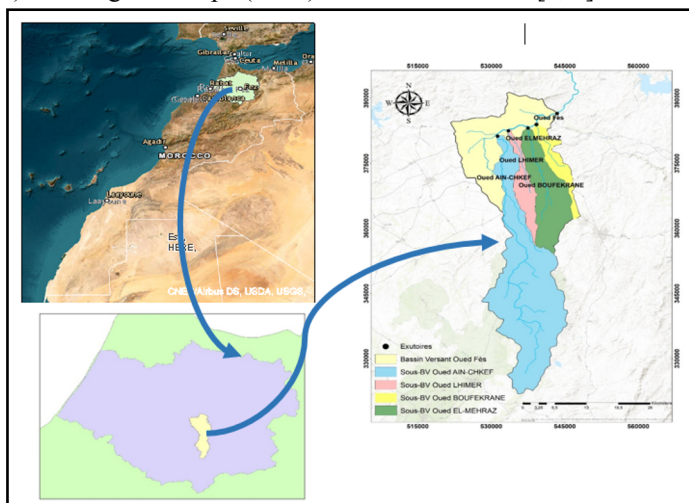


Fig. 1 Geographic location map of the study area on the scale of Morocco and the Sebou basin

The average annual precipitation shows a significant interannual irregularity with an irregular alternation of more or less humid periods and more or less dry periods. The driest periods record average rainfall of around 300mm while the wettest periods sometimes record average rainfall of more than 800mm [5-7]. The hydrological year 2009 is the wettest year, during the period 1981-2021, with an average precipitation of 1250mm.

3. Material and method

The cartographic database used in our study consists of topographic maps of the Fez region at different scales, the geological map of Fez, satellite images (landsat 8 and 9), the map of urban areas. Several software programs were used: ArcGIS, HEC-RAS and HEC-GeoRAS, The methodology adopted was based on the collection and cross-referencing of cartographic data and satellite images. Several steps are necessary to develop the thematic maps and finally the flood risk map [8-10].

The methodology begins with the extraction of different physiographic parameters of the watershed of the Fez wadi, the estimation of peak flows corresponding to the different return periods by the different empirical formulas (Mallet Gauthier, Fuller II, Fuller I, Hazen Lazarevich) [11, 17]

The second phase is that of the simulation of the hydraulic model. The development of this model consists of a coupling between ArcMap and HEC-RAS [18, 19] in order to establish the map of areas vulnerable to flooding.

4. Results and Discussions

The determination of the areas affected during floods was carried out by mapping these areas after extrapolations of GIS software. To highlight this risk in the city of Fez, we reestablished the beds of the water section that crosses areas on the basis of the topographic map, and rectified from a satellite browser that allows the visualization of the affected areas (the selected peak flows: $Q = 10$ and $Q = 100$) (Fig. 2).

After the hydraulic simulation carried out on HEC-RAS, the result of this processing is retained in the form of maps showing the extension of flood zones for different return periods (10 years and 100 years). The analysis of all the results obtained reveals the existence of several points threatened by the overflow of waters along the section studied.

Among the areas with high vulnerability to flooding, we can cite: The area located north of the Zouagha district resembles residential and industrial areas, which were built on the bed of the Fez river valley and near the El Himmer river outlet. This is the site most exposed to the risk of flooding. The second zone is located south of the Zouagha district built along the valley of Ain Chkef river. This observation leads us to conclude that the notion of flood risk must be taken into consideration when developing and expanding urban areas.

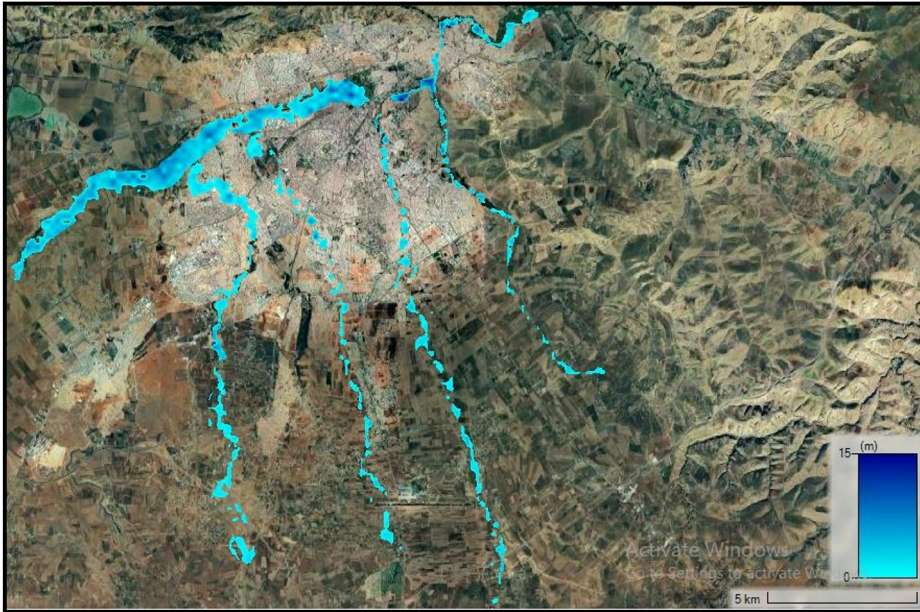


Fig. 2 Map of flood zones corresponding to the ten-year frequency flow (Q100)

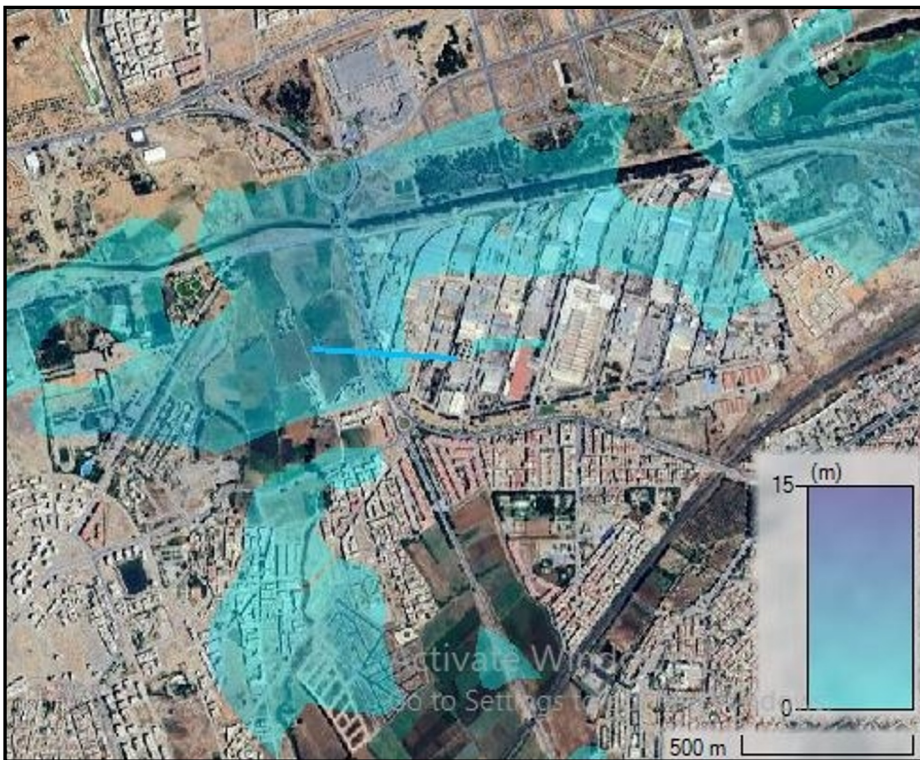


Fig. 3. Mapping of flood-prone areas to the north of the Zouagha district (housing and industrial zones) following hydraulic simulation with a 100-year frequency flow (Q100)

The area to the north of the Zouagha district, built on the bed of the Fes river valley and close to the outlet of the El Himmer river. This is the site most exposed to flood risk (Fig. 3). This figure shows the flooded areas after hydraulic simulation with a 100-year frequency flow.

5. Conclusion

The hydrological analysis, morphometric and physiographic characteristics of the Fez river watershed indicate a mild hydrological response. However, based on the analysis of the intensity of rainfall events, it appears that the watershed can generate floods mainly which are highlighted by the historical flood events in the city of Fez. The peak flows estimated by the empirical formulas are also significant and can generate catastrophic damages in the future.

Using the combined GIS and hydraulic modeling approach allowed the mapping of areas vulnerable to flooding in the Fez river watershed. These tools constitute decision-making tools in land management and planning.

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Author contribution

NE conducted and wrote the first draft of the manuscript under the supervision and effective suggestions of AEO, AE, AR, MHA and AVR. The other co-authors SI, AA, MM, AA, AR, ZA, AO, AKH, and MEH provided important suggestions and reviews. All authors read, corrected, and approved the final manuscript. NE served as the corresponding author.

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Consent for publication

All the authors have agreed to publish this article.

Competing interests

The authors declare that they have no competing interests.

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