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# A GIS based approach for the prediction of the dam break flood hazard – A case study of Zardezas reservoir "Skikda, Algeria"

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**Abstract**

The construction of dams in rivers can offer many advantages, however the consequences resulting from their failure could result in major damage, including loss of life and property destruction. To mitigate the threats of dam break it is essential to appreciate the characteristics of the potential flood in realistic manner. In this study an approach based on the integration of hydraulic modelling and GIS has been used to assess the risks resulting from a potential failure of Zardezas dam, a concrete dam located in Skikda, in the North East of Algeria. HEC-GeoRAS within GIS was used to extract geometric information from a digital elevation model and then imported into HEC-RAS. Flow simulation of the dam break was performed using HEC-RAS and results were mapped using the GIS. Finally, a flood hazard map based on water depth and flow velocity maps was created in GIS environment. According to this map the potential failure of Zardezas dam will place a large number in people in danger. The present study has shown that Application of Geographical Information System (GIS) techniques in integration with hydraulic modelling can significantly reduce the time and the resources required to forecast potential dam break flood hazard which can play a crucial role in improving both flood disaster management and land use planning downstream of dams.

**Key words:** *dam break, disaster management, flood hazard map, GIS, HEC-RAS, land use planning*

## INTRODUCTION

Dams provide many benefits for our society such as the supply of drinking and irrigation water, the generation of electric power and the flood protection. However, when a dam fails, large quantities of water are suddenly released, creating major flood waves capable of causing damages to downstream areas [WAHL 1998]. SINGH [1996] noted about 200 failures in the 20th century causing a loss of more than 8000 lives and damage worth millions of Euros.

Dam break analysis is performed as part of a dam safety assessment in order to evaluate downstream hazard potential for a dam failure which will assist the decision making authorities in land use planning and in developing emergency action plans to help mitigate catastrophic loss to human life and property [MARCHE 2008]. Accurate simulation of the dam break flood wave and its propagation along the downstream valley resulting from a potential dam failure are typically undertaken by hydraulic models [ZHOU *et al*. 2005].

In recent years, flood hazard assessment has considerably improved especially due to the use of geographic information systems in integration with hydraulic modelling. The major advantages of this integration are the possibilities to automatically prepare the geometric data and to import it into the hydraulic model. In addition, Data generated by the hydraulic model can be transferred to the GIS to produce inundation maps and to perform further analysis [ABDALLA 2009; PANDYA, JITAJI 2013].

Through a combination of the GIS extension, HEC-GeoRAS and HEC-RAS, engineers can use an available DEM to build the geometric file for a HEC-RAS model. Additionally, the GeoRAS extension has simple import and export capabilities to smooth the transition between creating the geometric file, running the model and displaying the results in GIS platform [SOLAIMANI 2009].

Numerous researches have been conducted to investigate the efficiency of this integration; [MOSQUERA MACHADO, SAJJAD 2007] combined HEC--RAS and GIS to assess the risk of flooding in Atrato River in Quibd´o, northwest of Colombia for floods of deferent return periods. The study has shown that hydraulic modelling and GIS has a sufficient range of functionality to be able to produce the flood extents and flood depth based on the available data.

YERRAMILLI [2012] introduced hybrid approach in identifying flood risk zones and assessing the extent of impact of the hazard by integrating HEC-RAS and GIS technologies. The developed approach was applied to the City of Jackson, MS. A high magnitude flood event, which was experienced by the study region in 1979, was simulated. The results indicated the efficiency of the developed hybrid approach in modelling the flood scenario, visualizing the spatial extent and assessing the vulnerability of the region.

CUREBAL *et al.* [2015] adapted the same approach to explain the formation mechanism of the 2009 flash flood event which occurred in the Keçidere basin in Turkey. The research consisted in simulating different return periods flood scenarios and compared the results obtained by the simulations against observed flood extent and depth at many locations. The results revealed that the 2009 flood event in Keçidere displays a similar value to around 500 year inundation recurrence interval. Furthermore, the research indicated that GIS is an effective environment for floodplain mapping and analysis.

The study presented herein aims at designing and implementing a systematic approach for predicting potential dam break flood magnitudes and assessing the associated downstream hazard by integrating HEC-RAS and GIS technologies. This approach, which allows visualizing and analysing the results in geospatial environment, was used to study the potential dam break flooding of Zardezas dam, a concrete gravity dam located in Skikda in the North East of Algeria.

## MATERIALS AND METHOD

### STUDY AREA

Located in Skikda, in the north east of Algeria, Zardezas Dam is a concrete gravity dam put into service in 1936. In 1974 the dam was raised by 12 m in order to attain a maximum height of 64 m above the deepest foundation level. It has actually a capacity of 18.1 $Hm^3$ at the full reservoir level of 197 m, and is used mainly to provide drinking water (21 $Hm^3$ per year), and irrigation (4 $Hm^3$ per year).


Fig. 1. Geographical location of the study area; source: own elaboration

In the downstream valley of the dam site there are several residential areas. Information about these areas is presented in Table 1.

**Table 1.** Information on the sub-areas downstream of Zardezas Dam

| Subarea | Distance to dam site, km | Population |
|---|---|---|
| Zardezas | 0.7 | 12 437 |
| Saïd Bousbaa | 5.9 | 14 302 |
| El Harrouch | 8.6 | 49 400 |
| Salah Bouchaour | 15.5 | 27 864 |
| Sahki Ahmed | 21.0 | 2 072 |

Source: the town hall of El Harrouch.

### METHODOLOGY

The proposed methodology that involves the integration of GIS and HEC-RAS flood simulation model is shown in Figure 2.

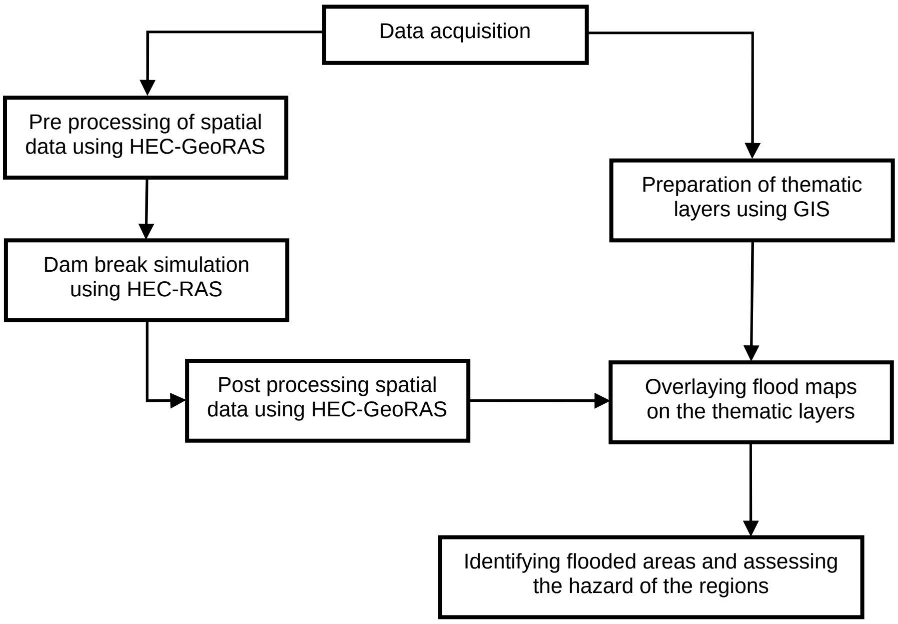


Fig. 2. Overall methodology; source: own study

## APPLICATION

### DATA ACQUISITION

Besides the characteristics of Zardezas dam and its reservoir, the present study required high quality satellite imagery and a digital elevation model (DEM) in order to identify areas susceptible to dam break flooding.

Two Satellite images were used in the research; a high-resolution image of the study area was taken from 'Google Earth' to draw the Geographic Information System (GIS) layers such as the stream centerline and the stream bank lines. In addition Landsat-ETM satellite image was used for visualization of the results.

Topographic data used to generate the DEM for the Saf-Saf valley were taken from the freely available (http://srtm.csi.cgiar.org) 3 arc second resolution Shuttle Radar Topography Mission (SRTM) dataset.

The SRTM data were subjected to the quality check with the available benchmarks elevations in topographic map of scale 1:50,000 of the study site collected from the National Institute of Cartography and Remote Sensing (INCT). SRTM elevations were very close with elevation differences of ±6 m.

### PRE-PROCESSING

The pre-processing of the geometric data (extraction of the physical characteristics of the study region) and the post-processing of the outputs that are required by the HEC-RAS dam break model are done by using HEC-GeoRAS.

To create the geometric file, the DEM is converted to a TIN (Triangulated Irregular Network) format. HEC-GeoRAS extension extracts the data from user-defined locations on the TIN. The data locations required are the streams centreline, stream banks, stream cross-sections, stream channel flow path, and flood plain flow paths. The process involves Satellite imagery to assist in defining the river geometry and the stream banks.

Figure 3 shows three main geometry data which are required for HEC-RAS, which consists of stream centre line, main channel banks, and cross section cut lines.

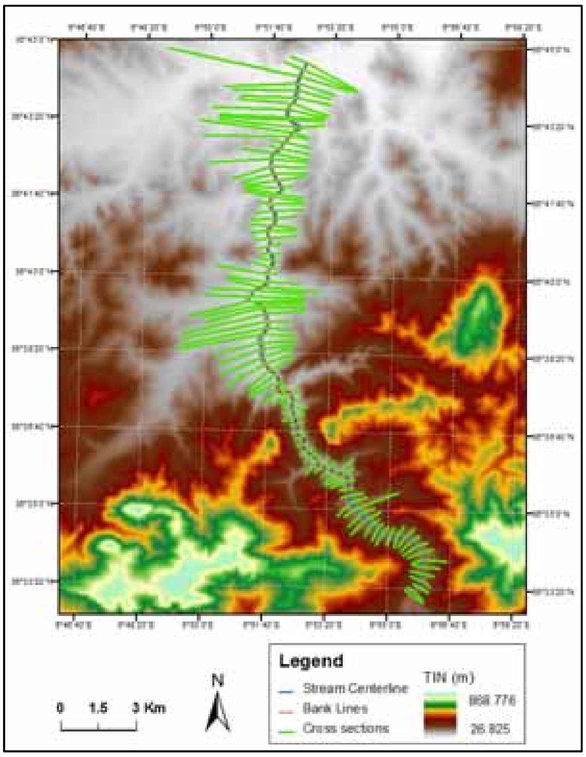


Fig. 3. Geometric data consisting of TIN, stream centerline, stream banks and cross-sections; source: own study

**DAM BREAK SIMULATION**

The dam breach simulation was conducted using the unsteady flow module of the HEC-RAS model. This component of HEC-RAS is based on the UNET model and uses a similar framework to solve the unsteady flow equations. It is based on an implicit finite difference solution of the complete one-dimensional continuity and momentum equations for unsteady flow coupled with an assortment of internal boundary conditions for simulating unsteady flows controlled by a wide variety of hydraulic structures [USACE 2010].

The dam breach parameters are set by following the information provided by the USACE user manual in estimating the breach parameters for a concrete gravity dam [GEE 2008]. The manual states that concrete gravity dams tend to have a partial breach as one or more monolith sections and the time for breach formation ranges from 0.1 to 0.2 h. For the Zardezas dam failure, the parameters are set with breach width as 158 m and failure time set to 0.1 h.

The scenario considered in this study describes a situation when the dam will fail during an extreme flood event, corresponds to the flow of 10 000 years probability. The initiation of the dam-break may start at the peak of the reservoir level 199 NGA. The flow hydrograph was used as boundary condition required in HEC-RAS at the upstream end of the river, the lower boundary condition was defined as normal depth for a channel bed slope of 0.002814.

Upon successful simulation of the dam break flow, the HEC-RAS results are exported to HEC-Geo RAS for post-processing in GIS platform.

**POST PROCESSING**

Post-Processing facilitates the automated floodplain delineation based on the data contained in the RAS GIS output file and the original terrain TIN. Using HEC-Geo RAS, the imported HEC-RAS outputs are processed with the TIN to generate the flood water surface extents, the flood water depth distribution and the flow velocity distribution.

When displayed with satellite imagery these maps can be used to identify the area impacted during the dam failure event as well as determines the characteristics of the floodwater for every pixel within these maps.

Figure 4 and figure 5 obtained from HEC-RAS simulations depict respectively water depth distribution and flood velocity distribution maps resulting from Zardezas dam potential collapse.

The area of spatial extent that is under flood waters is of 13.16 km$^2$ of area. The depth of flood waters ranges from 0.001 m to 24.21 m.

The velocity distribution map shows that the event is characterized by very high velocities especially in the first 8 km below the dam with values ranges from 20.25 to 3 m·s$^{-1}$. For the mild lower part of the studied Saf-Saf reach, the velocities range from 6 to 0.1 m·s$^{-1}$.

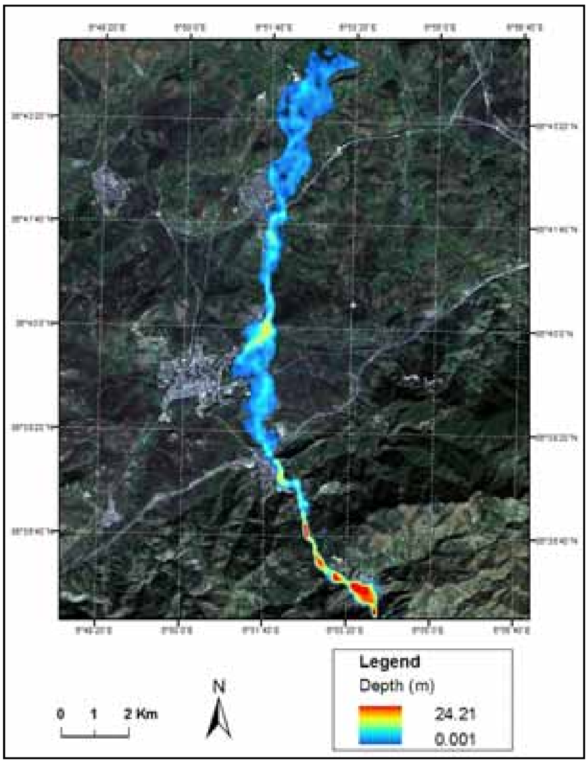


Fig. 4. Water depth distribution downstream of Zardezas dam; source: own study

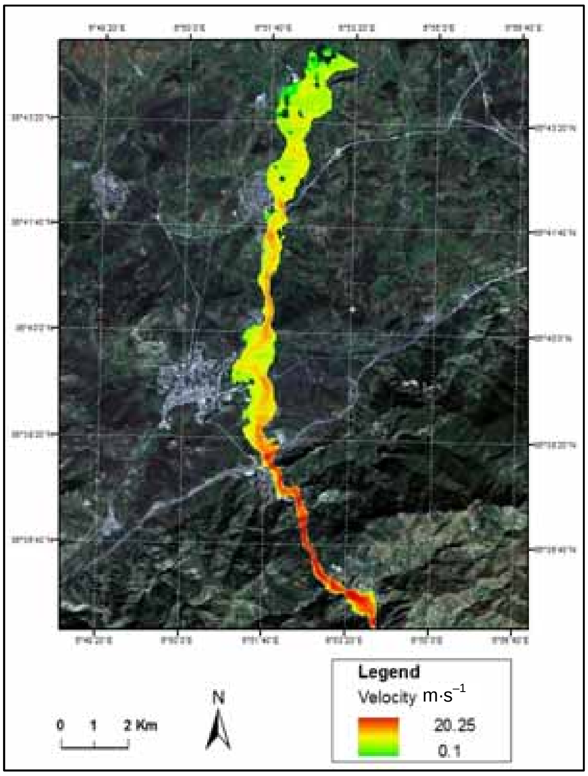


Fig. 5. Flow velocity distribution downstream of Zardezas dam; source: own study

Based on inspection of satellite imagery within the floodplain, it is clear that many residential areas located downstream of Zardezas reservoir will be affected in case of dam break.

The most percentage of inundation within the urban areas is expected to occur at Zardezas and Saïd Bousbaa with percentages of 49% and 23% respectively. While, at El Harrouch and Salah Bouchaour, percentages of inundation within the urban area are 7% and 11% respectively. Regarding Sahki Ahmed, the rural community will not be affected by the flooding as it falls out of the inundation zone.

## FLOOD HAZARD MAPPING

The threat to personal safety and to gross structural damage caused by floods depends largely upon the speed and depth of floodwaters. The greater these factors become, the greater the danger to people and property.

The depth-velocity hazard classification diagram considered in this study is based on the NSW flood development manual [NSW 2005]. As shown in the figure below hazard categories are broken down into high, medium and low hazard for each hydraulic category. These can be defined as:

– High hazard: possible danger to personal safety; evacuation by trucks difficult; able-bodied adults would have difficulty in wading to safety, potential significant structural damage to buildings;
– Low hazard: should it be necessary, truck can evacuate people and their possessions; able-bodied adults would have little difficulty in wading to safety.
– Medium hazard: In the transition zone highlight by the median colour, the degree of hazard is dependent on site conditions and the nature of the proposed development.

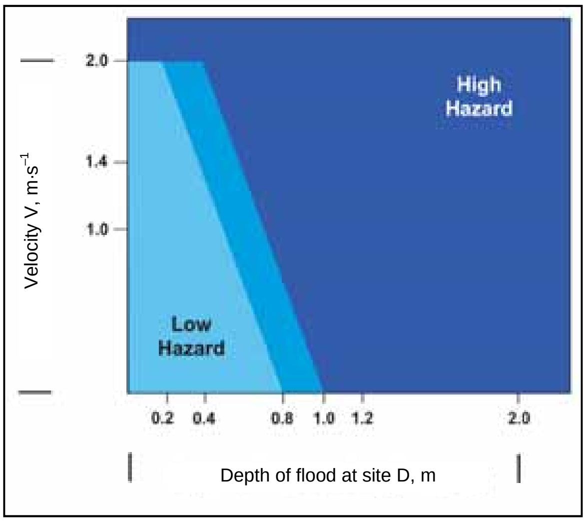


Fig. 6. Hazard zone classification as a function of velocity and water depth; source: NSW [2005]

Figure 7 presents the downstream hazard map resulting from the failure of Zardezas dam. This map was produced in the GIS by combining depth and velocity maps according to the diagram presented above.

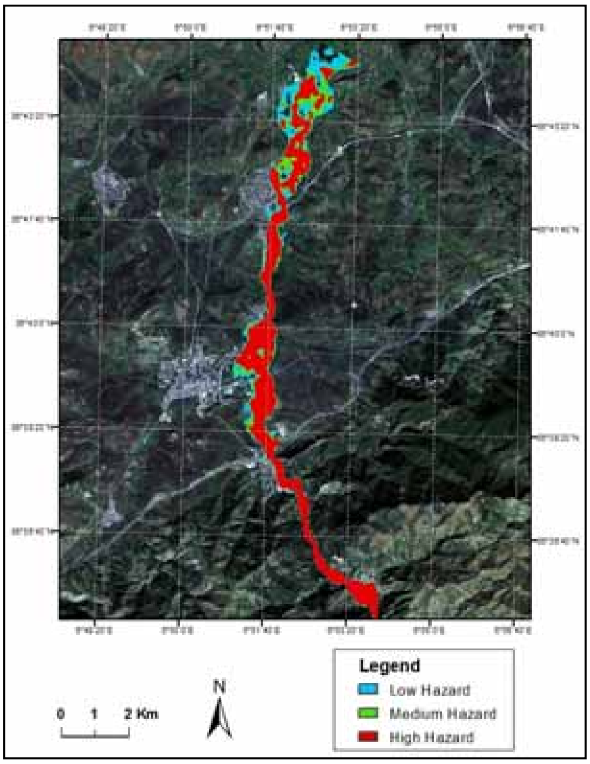


Fig. 7. Flood hazard map resulting from the failure of Zardezas dam; source: own study

It is clear from the hazard map that the severity of the flood water decreased as the dam break wave progress downstream. The most important damages to human life and property are expected to occur at the first 8 Km bellow the failed dam which includes Zardezas and Saïd Bousbaa villages, since many urbanized zones within the flooding extent are exposed to a high category of flood hazard. On the other hand, the damages will be limited at El Harrouch city and Salah Bouchaour village; since the flooding that extends into the floodplains will expose the urbanised areas to a medium to low level of flood hazard.

## CONCLUSIONS

This paper presented an effective approach to predict and assess downstream hazard associated with dam break flooding by the integration of hydraulic modelling and GIS.

One of the most important conclusions made from this study is that use of GIS in combination with the hydraulic model HEC-RAS by means of HEC-Geo RAS has the potential to reduce time and resources required for developing the analysis, mapping the results and performing hazard assessment.

Concerning the study area, the obtained results show that Zardezas reservoir represents a significant threat to downstream areas in the event of dam break; according to the hazard map; considerable loss to human life and property are expected to occur especially at Zardezas and Saïd Bousbaa vicinities.

The obtained results can be used by many stakeholders such as, urban planners, emergency responders and the community at risk, in formulating evacuation procedures for developed areas and considering new development in flood-affected areas.

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**Oussama DERDOUS, Lakhdar DJEMILI, Hamza BOUCHEHED, Salah Eddine TACHI**

**Zastosowanie techniki GIS do przewidywania ryzyka powodzi po przerwaniu tamy – przypadek zbiornika Zardezas w Skikda, Algieria**

STRESZCZENIE

**Słowa kluczowe:** *GIS, HEC-RAS, mapa ryzyka powodziowego, planowanie przestrzenne, przerwanie tamy, zarządzanie kryzysowe*

Budowa zapór na rzekach może przynosić wiele korzyści, jednakże ich przerwanie może skutkować poważnymi stratami, włączając w to utratę życia czy zniszczenie mienia. Aby zmniejszyć zagrożenia wynikające z przerwania tamy, należy uwzględnić charakterystykę prawdopodobnej powodzi w sposób realistyczny. W przedstawionej pracy zastosowano podejście polegające na zintegrowaniu modelowania hydraulicznego z GIS w celu oceny ryzyka potencjalnego zniszczenia betonowej zapory Zardezas zlokalizowanej w Skikda w północno-wschodniej Algierii. Do uzyskania danych geometrycznych z cyfrowego modelu wysokości użyto HEC-GeoRAS pracującego w GIS. Dane te następnie wprowadzono do HEC-RAS. Symulacje przepływu po przerwaniu zapory przeprowadzono z użyciem HEC-RAS, a wyniki przedstawiono w postaci mapy z użyciem GIS. Na koniec utworzono w środowisku GIS mapę ryzyka powodziowego na podstawie danych o głębokości wody i prędkości przepływu. Według tej mapy, potencjalne przerwanie zapory Zardezas stworzy zagrożenie dla znacznej liczby ludności. Badania wykazały, że zastosowanie technik GIS w połączeniu z modelowaniem hydraulicznym może znacząco zmniejszyć czas i ograniczyć zasoby niezbędne do prognozowania zagrożenia powodzią po przerwaniu tamy. Uzyskane wyniki mogą pełnić ważną rolę w zarządzaniu ryzykiem powodziowym i w planowaniu przestrzennym terenów położonych poniżej zapory.