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Three-dimensional simulation of a centennial flood of Mohammedia city in the the river of El Maleh – Morocco

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Abstract

The natural risks in general and the floods phenomena in particular have seen an impressive increase. This is mainly due to activity density growth in the risk areas. Currently, the territory management practice requires the best use of geospatial technologies in order to analyze, communicate and share the territory's visions.
A methodological process has been developed to properly assess the flood-risk in the city and its impact on urban planning. This process is split in two parts. The first part consists on putting in place a workflow that allows flood simulation over 100-year flood in 2D format. This simulation delimits the flood zone perimeters and produces a territory Flood map. Whilst the second part aims to explore the buildings altitudes and to visualize the submerged zones in 3D. For the sake of analysis simplification, a horizontal architectural cut was produced in order to view the waters level.

1. Introduction

The flood phenomena in Morocco has accentuated in the last two decades. This is due to population growth, economical, urban, agricultural, industrial and tourism developments. These developments have led on one hand to vulnerable areas occupation increase and to extreme phenomena of climate change on other hand. The flood has caused 68 events, 959 victims and 973 injured[1]. Geomatics sciences have brought great added value to various fields [1], especially in the scope of strategic urban planning due to the tremendous technological reach that exists nowadays.
The powerful GIS tools make it possible to manage, process, and analyze the spatial component. For this study, it is necessary to make attribute requests that allow us to find objects related to a spatial constraint such as the buildings that are in the floodable areas associated with a centennial period of return and are near the littoral radius of 1 km and the highway network. So, the GIS can easily respond to this request if the data are well structured in the Geographic Database (GDB).
Today, in order to make strategic decisions and have a thorough understanding of various current problems, 2D cartographic analysis is no longer sufficient [2]. To remedy this, it is now possible to display height or elevation. In short, we are talking about the third dimension (3D), which is really attractive and makes the visual field much closer to the reality of the ground. So, to restore a city's landscape, certain technical work should be done. First of all is the 3D database modeling, then setting up the databank, and after that, using the appropriate software in order to arrive at a three-dimensional exploration that includes the visual richness of elevation. This visual potentiality is more and more solicited in the urban planning field. The current tools allow us to design 3D digital mockups, to simulate town planning documents and new urban projects, to restructure districts, to fit out sites, to prevent urban extension, and even to build new cities.

[1] : BD CATNAT: International observatory for the monitoring of natural disasters risks: https://www.catnat.net/donneesstats/bd-catnat?view=stats(Country : Morocco)

1.1. Study Area

Fedala (*as it was called in the past*) or the city of Mohammedia is a prefecture belonging to the region of the Great Casablanca. Its geographical coordinates are: 33° 41' 23" North 7° 23' 23" West. It is limited to the north by the Atlantic Ocean to the east and to the south by the Province of Ben-Slimane and to the west by the prefecture of Sidi-Bernoussi (Figure 1).

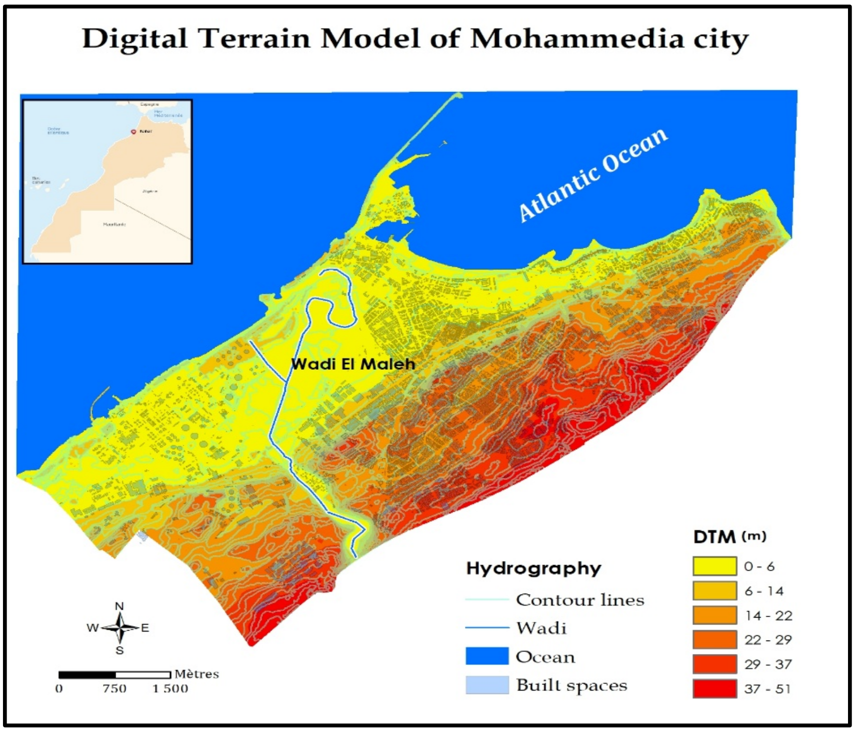

Figure 1 : The Digital Terrain Model of Mohammedia city

The city of Mohammedia is part of Corridor Strategic Coastline " Kenitra - Casablanca " presenting for the Kingdom a dynamic focus to multiple economic and political issues. At 70 km from Rabat and 24 km from Casablanca, the urban perimeter of the city extends on an area of 35 km². The population of the municipality has increased from 187.708 inhab in 2004 at 208.612 inhab in 2014 [3]. A rate of increase of 1.12%[2]. This relatively low growth is mainly due to the intra-city saturation and increasing change of mentality, which has led to a shift of the population toward the periphery due to the increased environmental pollution giving decision makers other problematic to solve.

Among other things, this evolution is mainly due to the industrial growth that it has started since independence, the increasing oil and port activities, and to its advantageous location between the two capitals: economic and administrative.

The city of flowers and stylish sports, as some like to call it, houses the main oil refinery in Morocco, SAMIR. On its outskirts, there is, the largest thermal power plant of the country, which supplies a large part of the Great Casablanca region. It also hosts the main tanker port of the kingdom, which refuels the SAMIR. The study area belongs to the western part of the coastal Meseta of Morocco also called Northern Morocco. It is distinguished by a low topography low, ranging below sea level at the level of the wet zone, sandy beaches and rocky flats. [4]

Hydrologically, there are two mouths that horizontally cross the city before arriving at the Atlantic coast knowas : River El-Maleh and River N'fifikh (Figure 2).

1. **River N'fifikh:** The watershed is an area of 830 km², formed for the essential by the Land shaly waterproof.
2. **River Mellah:** It is the most important of the coastal rivers. It starts in the north of the city of Khouribga on the northern edge of the plateau of phosphates and drains the northwest part of this

[2] : MS.CHAABANE : L'apport des SIG dans la gestion des risques naturels et la planification urbaine - Etude de cas : gestion des inondations dans la région de Mohammedia, p2 (2017)[2]

plateau. The surface ofits watershed is around 2800 km². This basin is equipped with three adjustments to know:

- The El Mellah DAM, put in water in 1932, for the development of the irrigation;
- The medium-sized Zamrine dam, built in 1951, which is currently completely silted up;
- The Boukerkour dam recently built to protect the city of Mohammedia against the floods.

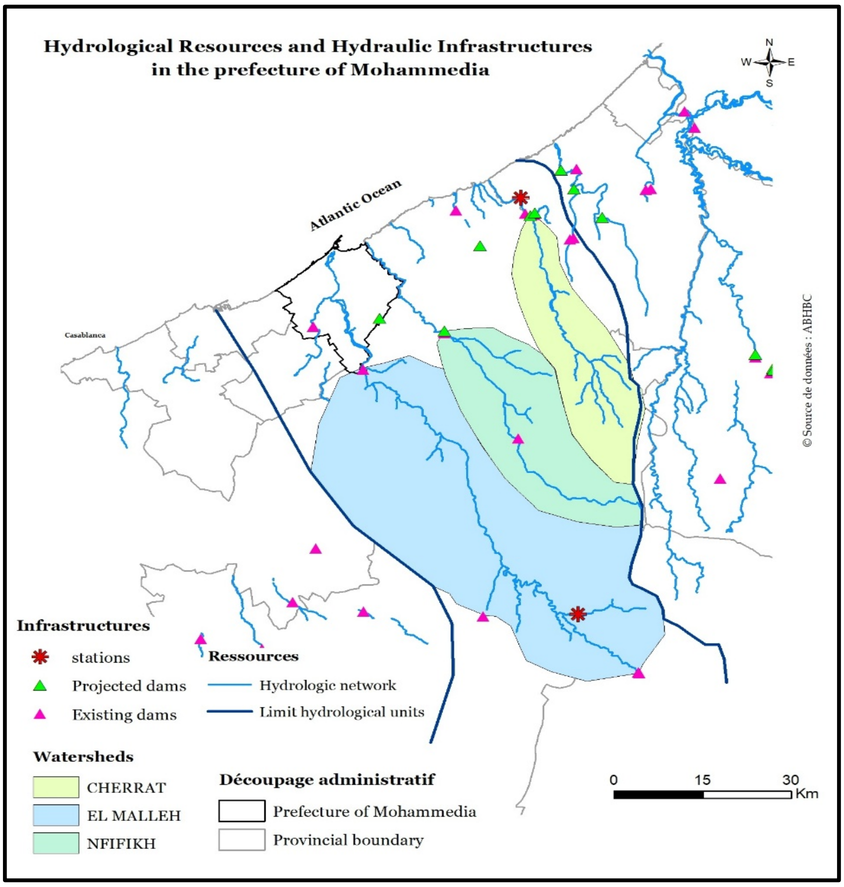

Figure 2 : Hydrological Resources and Hydraulic Infrastructures

2. Material and Methods

In order to properly assess the city-wide flood risk and its spatial impact on urban planning, a methodological process has been developed [5]. It is divided into two large parts (A and B), which involve a flood simulation in 2D and a 3D simulation of the submerged areas.

2.1. Part A

The first part is divided into three essential building blocks, including a spatial analysis, a hydrological analysis, and a hydro-spatial combination. This methodology consists of using geospatial tools to simulate floods at different periods—decadal, 20-year, 50-year, 100-year, 500-year, and millennial floods—and consequently to delineate in two dimensions the eventual flood-risk areas [6]. The result is a map summarizing the territorial stacks (all points of interest of the city) that are superposed with the flood scenarios identified at different return periods (Figure 3).

- *Spatial Analysis:*

In this step, the aim is to produce a set of spatial documents based on physical data stipulated in the process above, particularly the curvature map (Figure 4), the flow map, and the characterization of accumulated flows (Figure 5). Also, in order to produce these maps, the ArcHydro software is used, which qualifies as a tool that allows us to delimit and reveal watersheds in raster and vector formats and thus to define and analyze the hydro-geometric network [7].

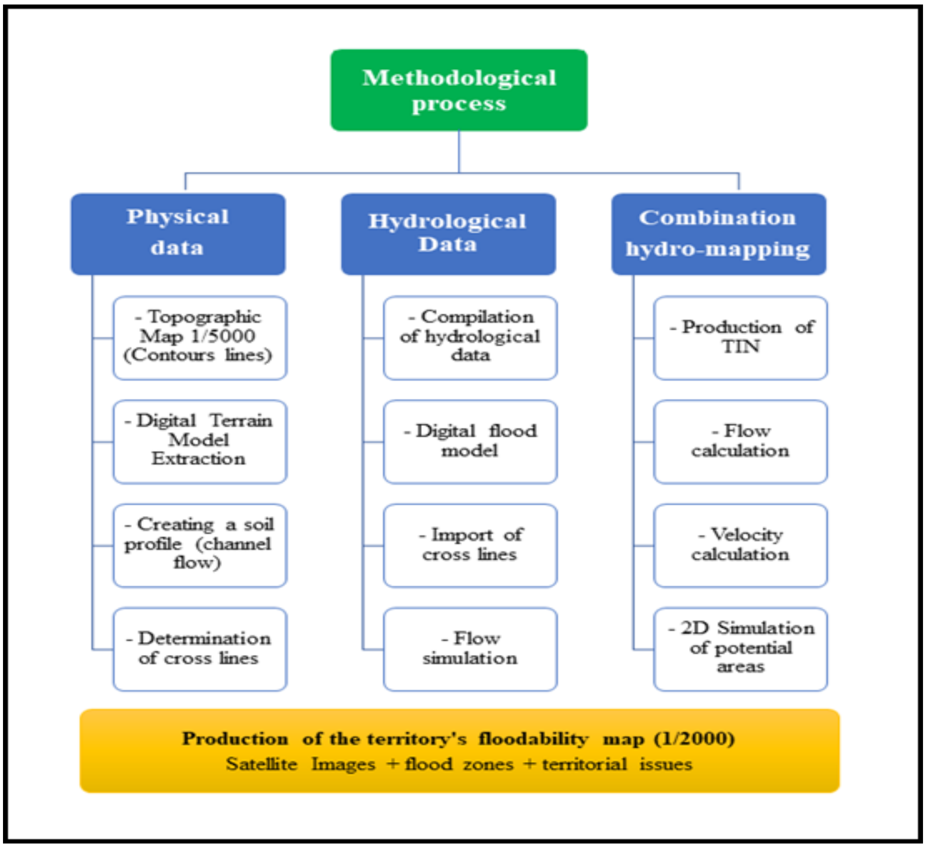

Figure 3: Methodological process of Part A

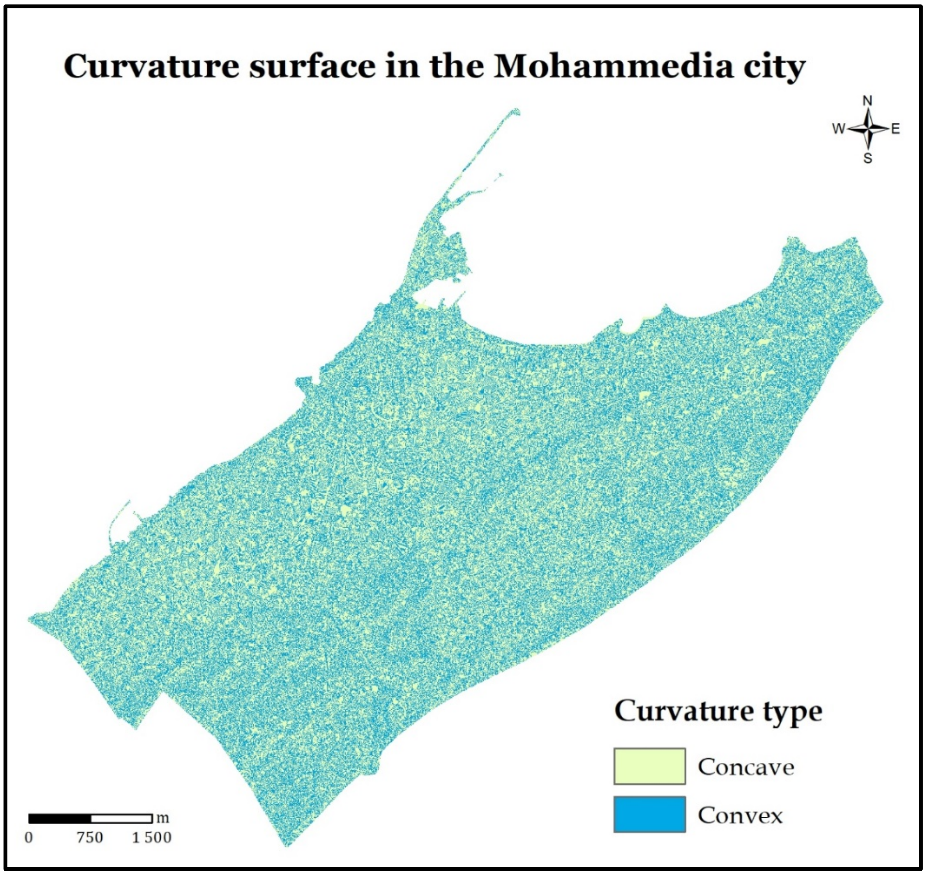

Figure 4: Curvature surface

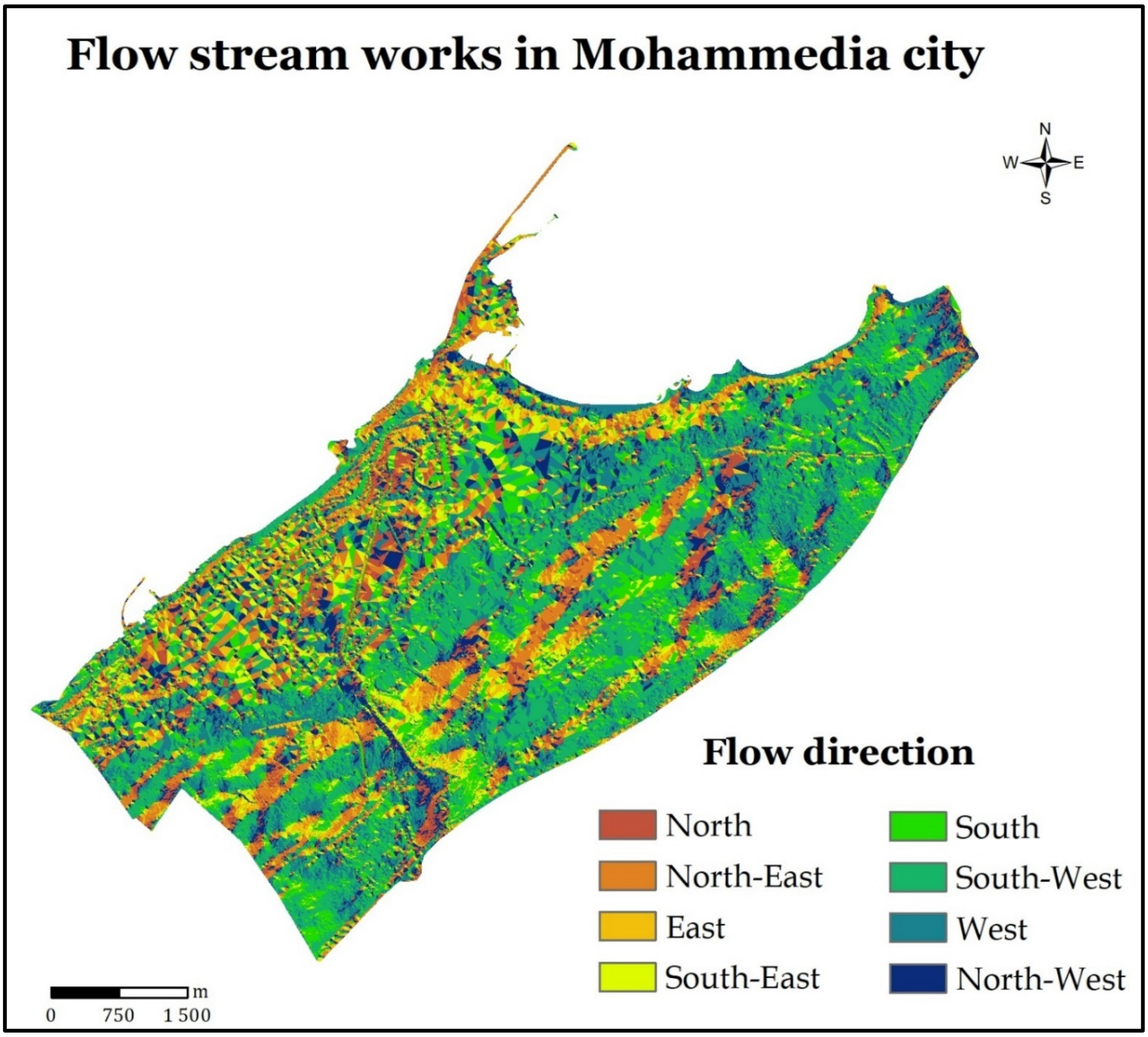

Figure 5: Flow stream works

The curvature tool allows us to describe the physical characteristics of a drainage basin and to understand the erosion and flow processes. The curvature value is used to look for soil erosion patterns and the distribution of water on land. Longitudinal curvature affects the acceleration and deceleration of the flow, which influences erosion and deposition. The planiform curvature influences convergence and flow divergence.

The determination of the flow direction is fundamental to the definition of the hydrological characteristics of a territory for each cell of the digital elevation model. The flow direction is the direction of the steepest descent or the maximum slope of each cell. It generates an output raster that is calculated by the maximum altitude variation of the eight adjacent cells in which water can flow. The method is called the "eight-way flow model (D8)" and is based on the approach proposed by Jensen and Domingue (1988)[3].

In short, the flow direction of water within the city of Mohammedia is practically in all directions but mentionned mainly in the southwest of the coastal city.

Regarding the characterization of accumulated flows, the aim of this step is to determine the different levels of water flow in the city of Mohammedia. To achieve this, the Model-Builder tool of ArcGIS software was used. It is an intelligent technique for developing a geo-processing workflow (Figure 6) that can automate spatial analysis and data management processes [8].

This model, which is schematized as a diagram, connects a series of sequences and spatial treatments of a set of operations which are hierarchized and executed one after another. The process to be performed is schematized below as an iterative spatial analysis model. Primarily, it is based on the Digital Elevation Model. The main operations to be executed are flow accumulation, filtering threshold, flow links, flow order, and the characterization of accumulated flows.

[3]: https://pro.arcgis.com/fr/pro-app/tool-reference/spatial-analyst/how-flow-direction-works.htm

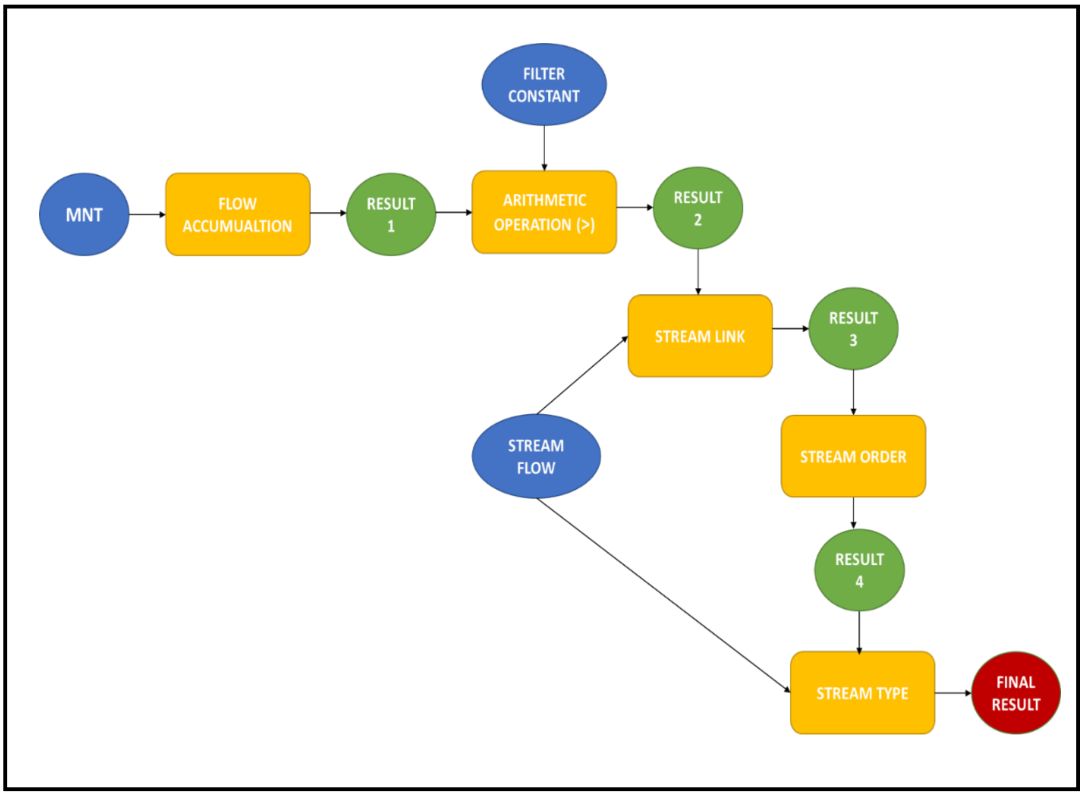

Figure 6: Classification diagram of water flow stream

Altogether, the setup workflow made it possible to characterize the accumulated flow of water in the city of Mohammedia. It should be remembered that the basic data obtained by the Digital Elevation Model are reliable and have probative quality, so the results obtained can be considered as reassuring and credible [9]. Thus, the identified cells are usually level 1 and 2. Nevertheless, the third- and the fourth-level flow accumulations are distinguished, and they represent areas called the "concentration zones of the flows" (Figure 7).

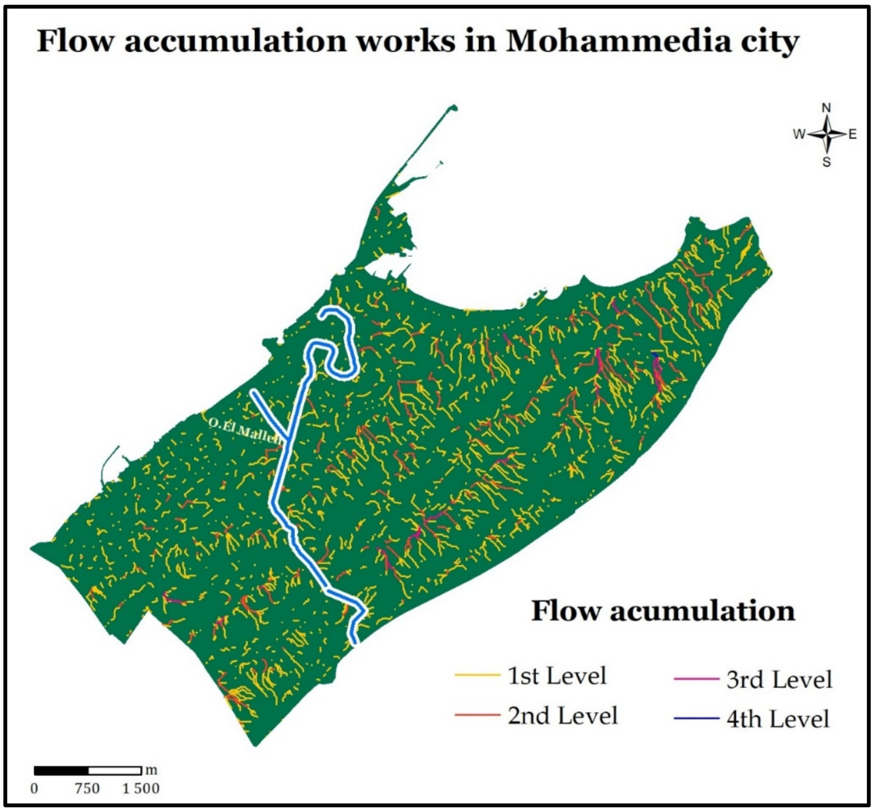

Figure 7: Flow accumulation works

- *Hydrological Analysis:*

The basic data that are used in the hydrological analysis are the numerical flood model, the triangulated irregular network "TIN," the floodplain boundary, and the flood-risk areas.
In this step, the aim is to determine a buffer zone that can receive possible floods. This zone is generated from the TIN and the numerical floods model. So, a special geoprocessing is used from the Geo-HecRAS tool to precisely delineate this floodplain [10].
The first step was the calculation of the water elevation surface based on the production of a new TIN for the river. Subsequently, the land was extracted from the elevation area. It was a long process that would ultimately determine the boundaries of possible flooded areas (Figure 8). The intensity of the hazard was calculated automatically according to the information and data previously input [11].

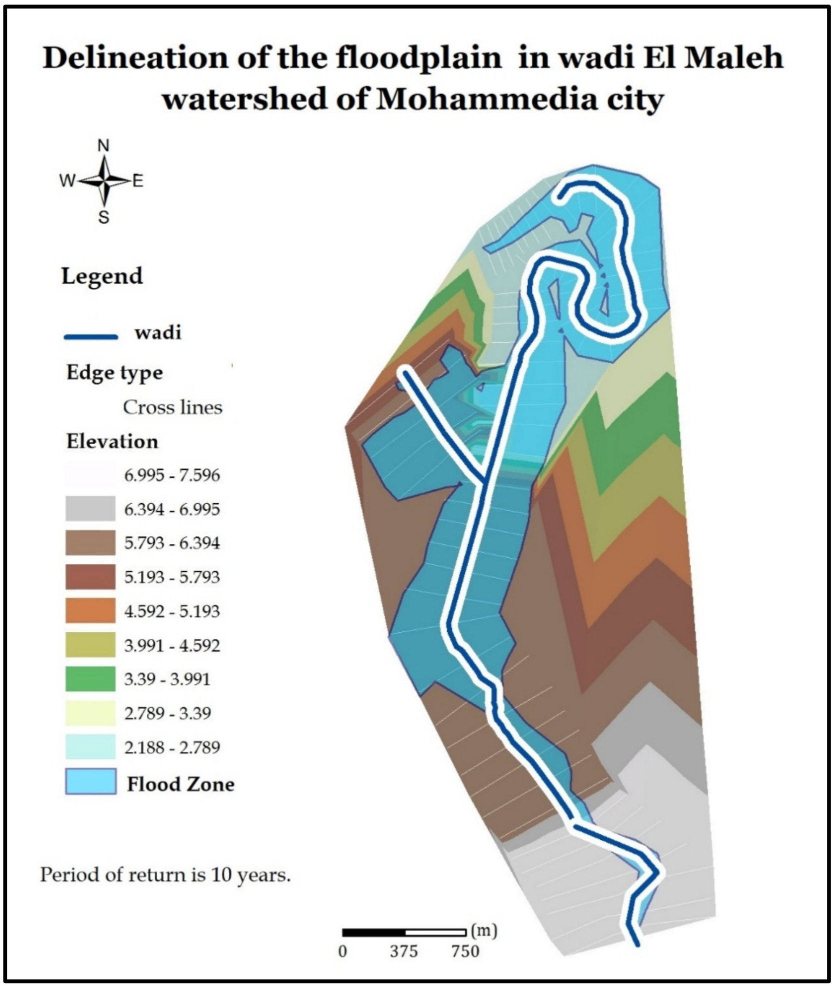

Figure 8: Delineation of the floodplain

2.2. Part B :

The second part is related to the 3D simulation of submerged zones through the creation of a 3D digital model and the visualization of the floods' height compared to that of built-up areas. So, in this part, the data resulting from digital reproduction were combined with the Digital Elevation Model (DEM), ensuring the easy transit from the second to the third dimension [12].

<u>From 2D to 3D:</u>

The photogrammetry data restitution was conceived under a computer-assisted drawing (CAD) tool. And in order to use it in the GIS environment, it was necessary to trigger a workflow capable of processing, handling, and displaying. This process consists of five essential steps, including CAD conversion to GIS, projection definition, layer extraction, data crossover with the Digital Elevation Model, and finally, displaying the 3D buildings.

- <u>*DEM Crossing:*</u>

Given the availability of information in the photogrammetry data restitution of the city of Mohammedia and after the definition of the Moroccan projection adapted to the study area, it was necessary to extract all the data in separate layers [13]. In this step, the goal was to stack layers extracted from the photogrammetry data restitution with the Digital Elevation Model, which contained the data relating to the elevations. Moreover, a spatial join was made to assign the elevation data to the buildings layer.

- <u>*Display buliding in 3D:*</u>

Now, the Z data were attached to the building layer. The idea was to display these elevations through a three-dimensional staging. The tool used for this purpose was ArcScene 10.2, as this software specializes in 3D simulation datasets. The function used for this purpose is called “extrusion,” which is a process of vertical stretching of a flat 2D shape in order to create a 3D object through the altimetric values. The result obtained gives a global overview of the morphology of the city.

3. Results and discussion

A simulation of centennial floods was developed in order to determine the flood risk in Mohammedia. To do this, a geographic database (GDB) was set up to facilitate the creation of the territorial stacked map. This Geodatabase identified all economic stacks (industrial sites, warehouses, activities, etc.), housing, transport networks (national-regional roads, motorway, railways), and hydrology (stream of rivers, channel of shedding, tablecloths, etc.). The aim was to make a cross between the boundary of the flood and the territorial stacks map in order to carefully determine the areas at risk upon the appearance of a 100-year flood.
The above result (Figure 13) shows that the great flooded area is the one existing along the river of El Maleh, notably the wet zone considered as non-buildable area.

3.1. 3D Simulation of a centennial flood:

The elevation component «Z» of the built-up areas in Mohammedia provided a fantastic and immersive overview while joining usefulness (the delineations of the flooded areas) with pleasantness (the elevation levels of the floodwaters) (Figure 9). Therefore, the visualization of the result in 2D can determine the submerged zones. However, the 3D visualization allows one to see the height of the floods and to make spatial queries on the elevation data. The simulation of a 100-year flood in 3D allows us to draw the reality of the city in case of the appearance of a possible catastrophe. Decisionmakers will be stimulated by the immersive result and can have a proper look at the flood’s impact on the population and their shelters, on employment, and on the damage to buildings and infrastructure, and consequently to post-estimate the costs of rehousing the civil society and the related problems.

3.2. Zoom on the floodable areas:

The 3D simulation of a centennial flood identifies of three flooded areas: the coastal industrial zone (IZ) and especially the oil district, the industrial zone Hassan II, as well as the industrial zone of the port and the neighboring buildings.

- <u>*Coastal industrial zone (IZ)*</u>

The first area to be damaged by a 100-year flood is the coastal zone, and more specifically, the Kingdom’s only thermal power station, and the oil district, notably through the refinery station and the big neighboring warehouses (Figure 14). Although this area is large, with a boundary exceeding 260 ha, it should be noted that 21.16 ha would be flooded in its northeastern part, notably an approximation of 8% of the total area. The height of the waters in this area will reach 1m, which will undoubtedly affect the 20 existing factories and consequently increase the risks and lead to a socioeconomic handicap given the number of jobs they support.

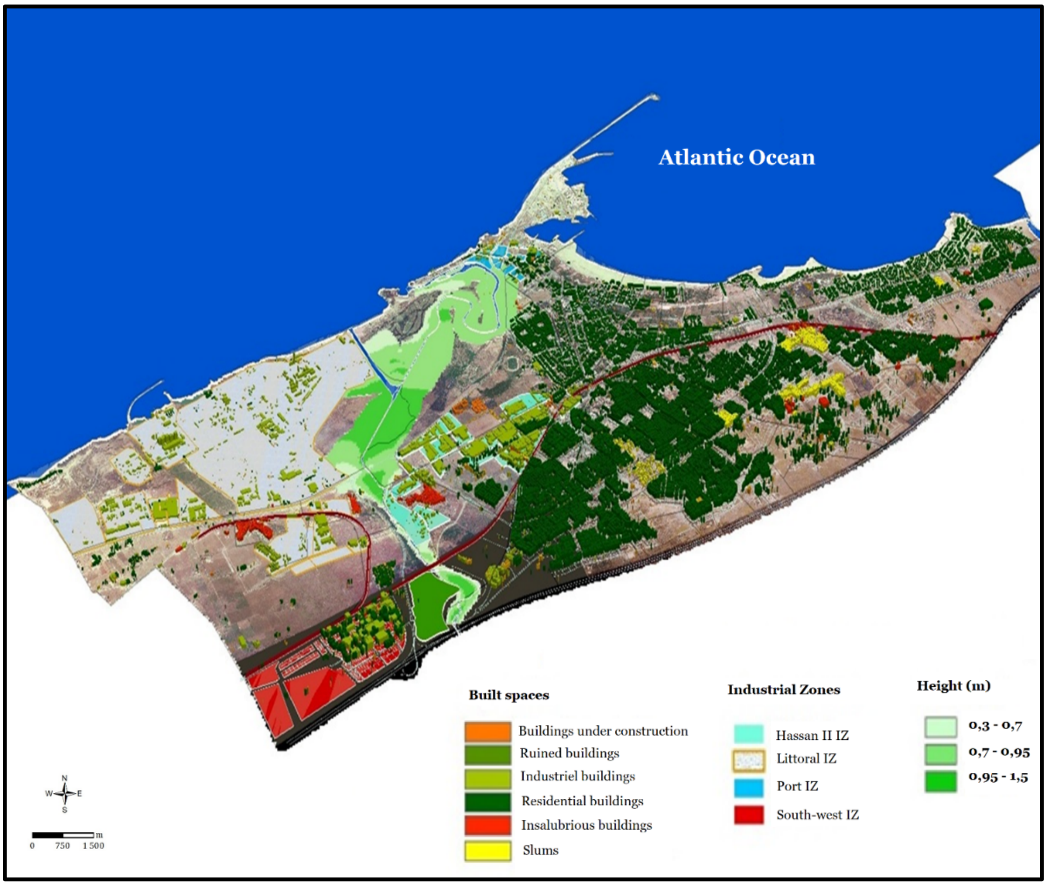

Figure 9: 3D Simulation of a centennial flood

Figure 14: 3D zoom of centennial flood in the coastal industrial zone of Mohammedia city

Conclusion

The flood risk area is a dynamic and evolving process which is based on technical work (topographic survey, identification of minor and major riverbeds, characterization of flooded areas, study of previous or reference floods, etc.) and is confirmed by the tools and digital processes of geomatics sciences [14].

In this research, the third dimension was used to explore, visualize, and analyze the built-up areas impacted by a 100-year flood. This centennial flood could reach a height of 1.5 m in the oil district and the Gulf zone in Mohammedia. Although the only refinery is temporarily in "standby" mode, at the appearance of such flood, the district could suffer an undeniable calamity and significant damage and thus handicap socioeconomic development.

Structural measures have proven effective and efficient in mitigating flood risks in the city. For Mohammedia, some proposals are strongly recommended, such as

- Increasing the maximum water discharge capacity during floods while strengthening the protective dikes downstream to contain streams;
- Continuously maintaining watercourses from upstream to downstream, especially the load-shedding channel;
- Developing smart sanitation and managing the rainwater and storage-water system to facilitate infiltration of precipitation into the soil;
- Prohibiting all construction along the river that could destabilize or influence natural watercourses;
- Developing an early warning system to quickly notify stakeholders and take the necessary measures to protect citizens;
- Setting up the emergency and evacuation plans for the population.

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