

Cartographie de la vulnérabilité des inondations dans la préfecture de Mohammedia à l'aide de la méthode d'analyse hiérarchique multicritère

Mapping of flood vulnerability in Mohammedia prefecture using the multi-criteria hierarchical analysis method.

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Résumé

Afin de lutter contre les inondations urbaines dans la préfecture de Mohammedia et d'aider les gestionnaires à identifier les mesures appropriées pour y faire face, cet article présente une analyse de vulnérabilité basée sur la méthode d'analyse hiérarchique multicritères (AHM). Cette méthode d'aide à la décision permet de calculer un indice de vulnérabilité prenant en compte les composantes humaines, environnementales et matérielles. Elle permet ensuite de réaliser une cartographie globale des risques, à partir des résultats de l'évaluation de la vulnérabilité, tout en respectant le périmètre des zones à risque. Cette cartographie a été rendue possible grâce au système d'information géographique ArcGIS, qui a permis la fusion de ces deux variables. L'objectif est d'identifier le risque que les inondations urbaines représentent pour la population et les infrastructures.

D'après les cartes de la vulnérabilité, l'indice le prédominant au niveau de Mohammedia, est celui de la vulnérabilité humaine, qui se traduit par le risque sur la population. Ainsi il existe d'autres risques qui concernent les infrastructures du réseau routier et les collecteurs des rejets des eaux pluviales, en plus le risque qui présente Oued Maleh et le risque des zones industrielles.

La visualisation directe du risque à l'aide de la superposition des couches d'aléas et de la vulnérabilité permet de classer les zones vulnérables par rapport à l'inondation et qui peuvent avoir plus de dégâts. On a trois zones à risque d'inondations au niveau de Mohammedia qu'elles sont classées selon la vulnérabilité aux dégâts.

Mots clés : AHM, Vulnérabilité, Cartographie des risques, ArcGIS, Inondations urbaines

Abstract

In order to combat urban flooding in the Mohammedia prefecture and help managers identify appropriate measures to deal with it, this article presents a vulnerability analysis based on the hierarchical multi-criteria analysis (HMA) method. This decision-making method calculates a vulnerability index that takes into account human, environmental, and material components. It then enables comprehensive risk mapping based on the results of the vulnerability assessment, while respecting the boundaries of the risk areas. This mapping was made possible by the ArcGIS geographic information system, which allowed these two variables to be merged. The aim is to identify the risk that urban flooding poses to the population and infrastructure.

According to the vulnerability maps, the predominant index in Mohammedia is that of human vulnerability, which translates into risk to the population. There are other risks relating to road infrastructure and storm water drainage systems, in addition to the risk posed by Oued Maleh and the risk to industrial areas.

The direct visualization of risk using overlapping hazard and vulnerability layers makes it possible to classify areas that are vulnerable to flooding and likely to suffer greater damage. There are three flood risk areas in Mohammedia, which are classified according to their vulnerability to damage.

Keywords: MHA, Vulnerability, Risk mapping, ArcGIS, Urban flooding

Introduction

While the hazards (physical phenomena of a given nature, intensity and occurrence) associated with flood risk have been the subject of a large number of specific studies, more recent studies have focused on vulnerability studies. However, they are rare and have in common that they can be relatively improved. From a general point of view, vulnerability is considered as the propensity of a given society to suffer damage or dysfunction in the event of the occurrence of a natural or anthropogenic phenomenon [1]. In this study, we focused precisely on vulnerability, which is a response to randomness. Indeed, within any territory there are human, material and environmental issues that allow it to function, but which can also interact to generate and spread their vulnerability outside the affected [2,3,4].

This article therefore aims to develop a methodology for flood risk management focused on vulnerability. This will be applied to Mohammedia, but it has the particularity of being transferable to any area. The notion of risk is perceived here as the possible occurrence of a hazard on potentially vulnerable issues [5,6,7,8,9,10].

The method adopted in this article is the multi-criteria hierarchical analysis method, which is a method adapted to multi-criteria decision-making problems, with several solutions satisfying a set of criteria. The approach of the method consists in simplifying the problem by breaking it down into a hierarchical system.

The first objective of this method is to qualify and quantify this vulnerability spatially, adaptable to all types of hazards and in all places, taking into account all the issues at stake in the study areas, as well as human, material and environmental issues. This step of inventorying the elements exposed is followed by the identification of vulnerability factors for each of them, the objective of which is to try to produce a global vulnerability indicator. The second objective corresponds to the merging of vulnerability with hazard zoning. Direct visualization of risk using the superposition of hazard and vulnerability layers allows to classify vulnerable areas in relation to the flood and which may have more damage.

1. Materials and methods

1.1. Study area

1.1.1. Location

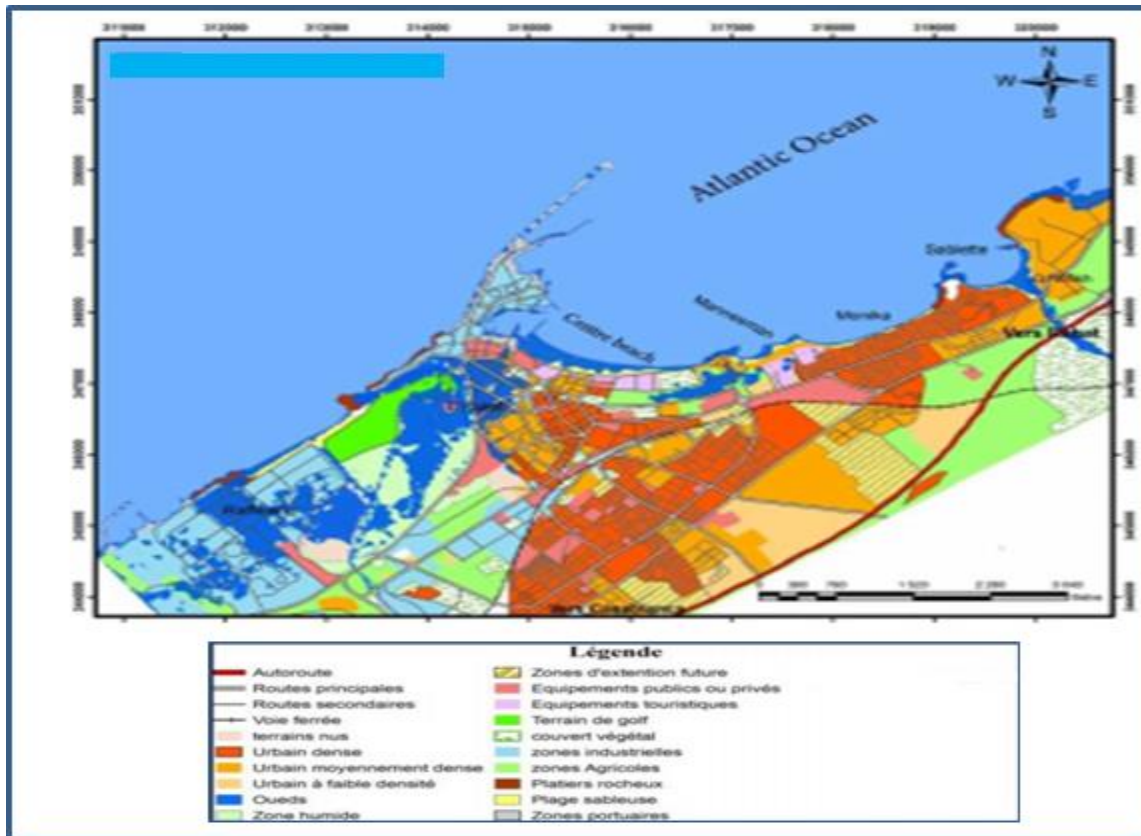
Mohammedia is located between Rabat and Casablanca, in the Greater Casablanca region. The urban perimeter of the city extends over 3,320 hectare and is located between the mouths of Oued El-Maleh and Oued Nfifikh.

It houses Morocco's main refinery, the Samir. There is also the country's largest thermal power plant, which supplies most of the Greater Casablanca region. It also hosts the kingdom's main oil port, which supplies the Samir.

1.1.3. Land use planning

The evolution of land use at Mohammedia level has increased the waterproofing of the soil (buildings, roads, car parks, etc.), which limits rainfall infiltration and increases runoff, which often leads to saturation and backflow of the rainwater sanitation network.

Figure 3: Land use in Mohammedia



Source: urban agency

1.1.4. Demographic data

Mohammedia is changing demographically as fast as the city of Casablanca. According to the 2014 census, the population of Mohammedia Prefecture reached 404,648 people, a relative variation of 25.6% and an average annual growth rate of 2.3% over the period 2004-2014. More than half of this number (51.6%) resides in the municipality of Mohammedia, whose population changed between 2004 and 2014, according to the average annual growth rate of 1.01%.

1.2. Methodology

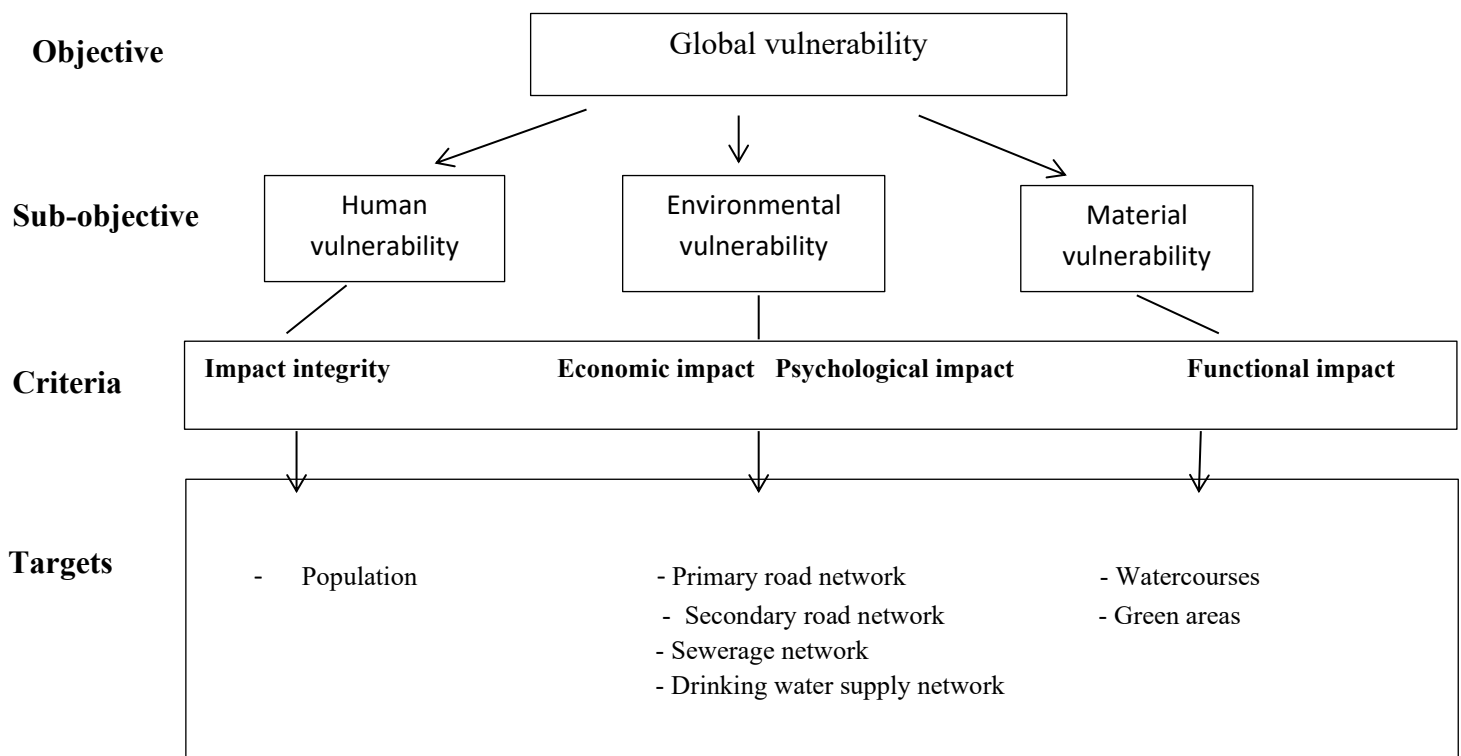
The multi-criteria hierarchical analysis is a tool to assist in the decision developed to solve problems complex multi-criteria that include aspects of qualitative and quantitative in a process decision-making. Several decision support methods exist, such as comparison by criteria, ordinal method or multi-criteria decision support method. The latter, in which we are specifically interested, consists in ordering the

solutions on the basis either of a single criterion or of different criteria understood in their plurality. The objective is to highlight one or more proposals that most closely reflect the objectives sought [11]. The purpose of choosing this method is to analyze vulnerability in Mohammedia by ranking the various issues according to their importance or sensitivity to the hazard. This proposed vulnerability analysis therefore seeks to produce an overall vulnerability indicator through the application of the multi-criteria hierarchical analysis method. The use of a Geographic Information System will make it possible to spatialize the elements exposed and produce a synthetic map while allowing for analytical questioning (human, material, and environmental vulnerability).

1.2.1. Hierarchical structuring of vulnerability criteria

The first step in the multi-criteria hierarchical analysis method consists in constructing a hierarchy that aims to describe the system under study. The hierarchy (fig.3) created proposes a structured vision of the problem in terms of objective, criteria and alternatives.

Fig.4: Hierarchical structure of the vulnerability



Source: Saaty

The assessment of global vulnerability requires the assessment of the vulnerability of human, environmental and material targets. Their vulnerability depends on the impacts of runoff on them.

Three types of impacts were selected as criteria, health or integrity impacts express the effects of runoff on the integrity of human, environmental or material targets.

For the latter two types of targets, integrity impacts were divided into two sub impacts depending on whether the runoff affects the physical or functional integrity (the target's ability to perform its function

after being impacted) of the target. Economic impacts express the effects of runoff on targets in terms of costs that can be direct (costs related to the destruction of the target) or indirect (rehabilitation costs, operating loss, technical unemployment...). Finally, psychological impacts express the effects in terms of influence on a group of people. For human targets, two types of psychological impacts have been identified: the panic effect and post-disaster trauma.

At the last level of the hierarchy are the alternatives that correspond here to the human, material and environmental targets likely to be impacted.

1.2.2. Use of expert judgement in vulnerability assessment

This quantification is based on two-by-two comparisons of issues, using a specific scale based on Saaty's criteria (1980 – tab.1) [12]. This evaluation grid has the advantage of measuring subjective as well as formally quantitative judgments, in order to measure the priority of one of the issues in the hierarchy over another. Thus, each of them is compared to all other issues of the same order, and relative to each of the issues at the higher level. The expert is thus asked to assess the vulnerability of issues of the same nature, which are at the same level of the hierarchical breakdown.

Tableau1: Binary comparison scale used to assess territorial vulnerability

Numerical weighting	verbal ponderation
1	Equal vulnerability of both elements
3	One element is a little more vulnerable than the other
5	One element is more vulnerable than the other
7	One element is much more vulnerable than the other
9	One element is absolutely more vulnerable than the other
2, 4, 6, 8	Intermediate values between two similar assessments
1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9	Reciprocal values of previous assessments

Source: adapted from Saaty, 1980

1.2.3. Reflection on the analytical framework

The aim of the AHP is to establish vulnerability weights between the issues at stake in Mohammedia. However, once these weights have been established through functions and for operational use, they must

be visually translated into cartographic work. It is therefore necessary to use a GIS to spatialize process, store and analyze heterogeneous information about the issues. The GIS thus makes it possible to map the issues quantitatively but also qualitatively according to their vulnerabilities while allowing an analytical interrogation [13,14,15].

However, the graphical representation of the issues is presented in different spatial natures: surface, linear or point. This raises the question of the area of exploration of the issues because they must be rationalized for their combination.

In order to work on the raw data (and not relative according to area), to facilitate the comparison of areas and the understanding of the results, it was decided to standardize the size and shape of the exploration sectors by square grid [16].

Surface, linear or point issues are converted by GIS into mesh form, and quantified according to their areas, lengths or sum of elements in the mesh. The size of the meshes must be adapted to the level of accuracy of the data, but also to the space studied itself and its own problems. A 500-metre-long grid is used.

The use of a finer grind has therefore made it possible to refine the structure of the issues quantitatively and qualitatively, and thus to limit the standardization of information, because the issues are not always distributed evenly throughout the grid.

Then, the issues are weighted using the vulnerability functions previously established by the experts, both according to their nature, but also according to their hold on the ground in each of the meshes. A quantization factor is then defined as a dimensionless variable, ranging from 0 to 1. The value 0 indicates an absence of the issue in the mesh, and the value 1 means that the quantity of this issue is the highest compared to other meshes. This factor therefore makes it possible to obtain a standardized quantification for each of the issues and standardized representations of vulnerability, regardless of the nature of the issues and the level of hierarchical decomposition considered.

1.2.4. Vulnerability functions and mapping processing

The results obtained make it possible to assess the vulnerability of the issues by establishing weighting functions. They group all the issues at the same level of the hierarchical decomposition (fig.3) by assigning them a weight according to their respective vulnerability. For example, for the first line of the hierarchical decomposition, the weighting is as follows:

Global vulnerability= **0.70** x Human Vulnerability + **0.10** x Environmental Vulnerability + **0.20** x Material Vulnerability

This function shows the predominant share of human issues.[17] even describes them as "supreme challenges to be preserved". However, the shares of environmental and material issues are not

equivalent. Indeed, according to experts, material issues are more vulnerable to flooding than environmental issues. Similarly, vulnerability functions are obtained for each level.

2. Results of the multi-criteria vulnerability analysis

The concrete application of the AHP is based in this study on the construction of vulnerability maps. Figure.4 represents overall vulnerability, as well as human, environmental and material vulnerabilities.

Figure 5: Mohammedia’s global vulnerability map

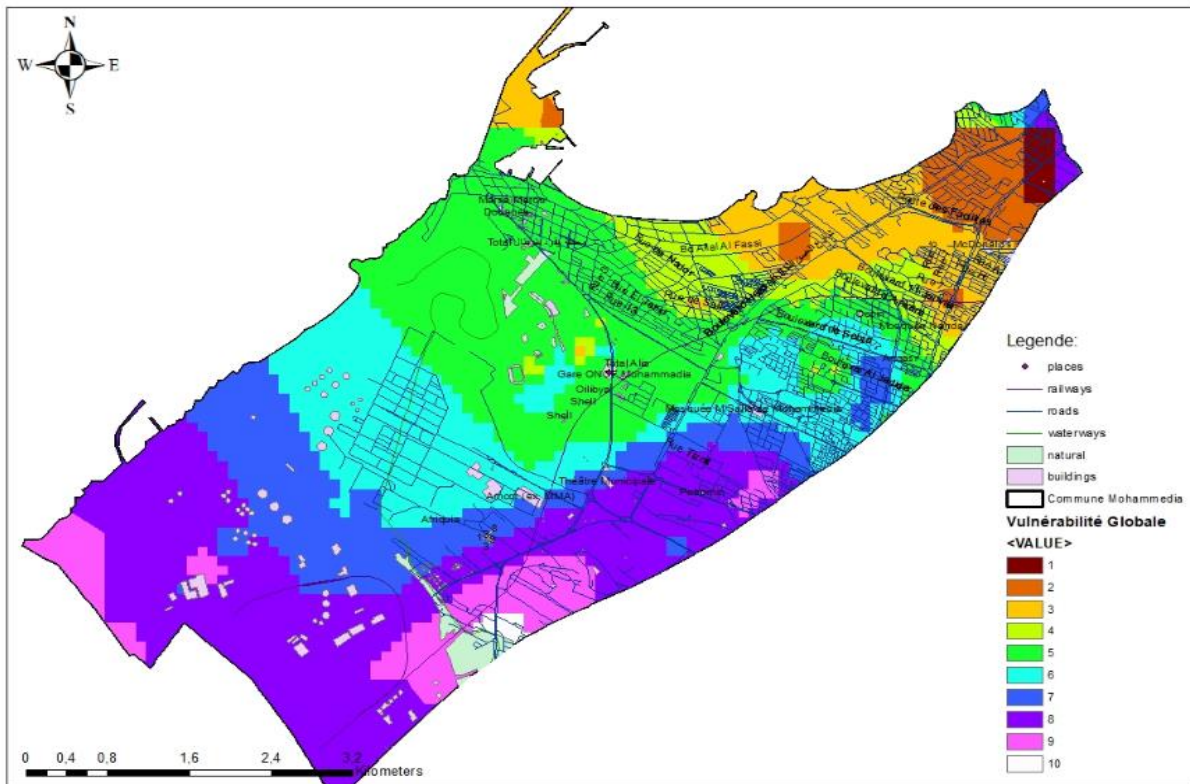


Figure 6: Mohammedia's Human Vulnerability Map

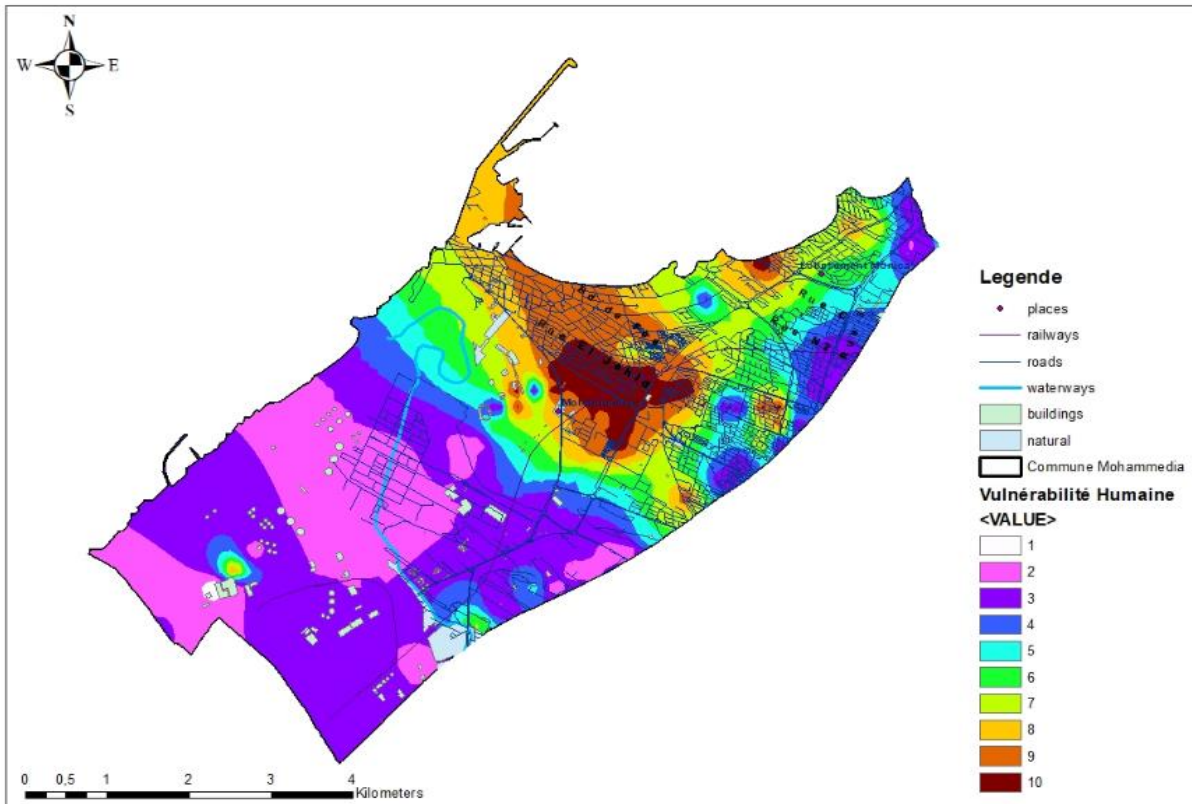


Figure 7: Mohammedia's material vulnerability map

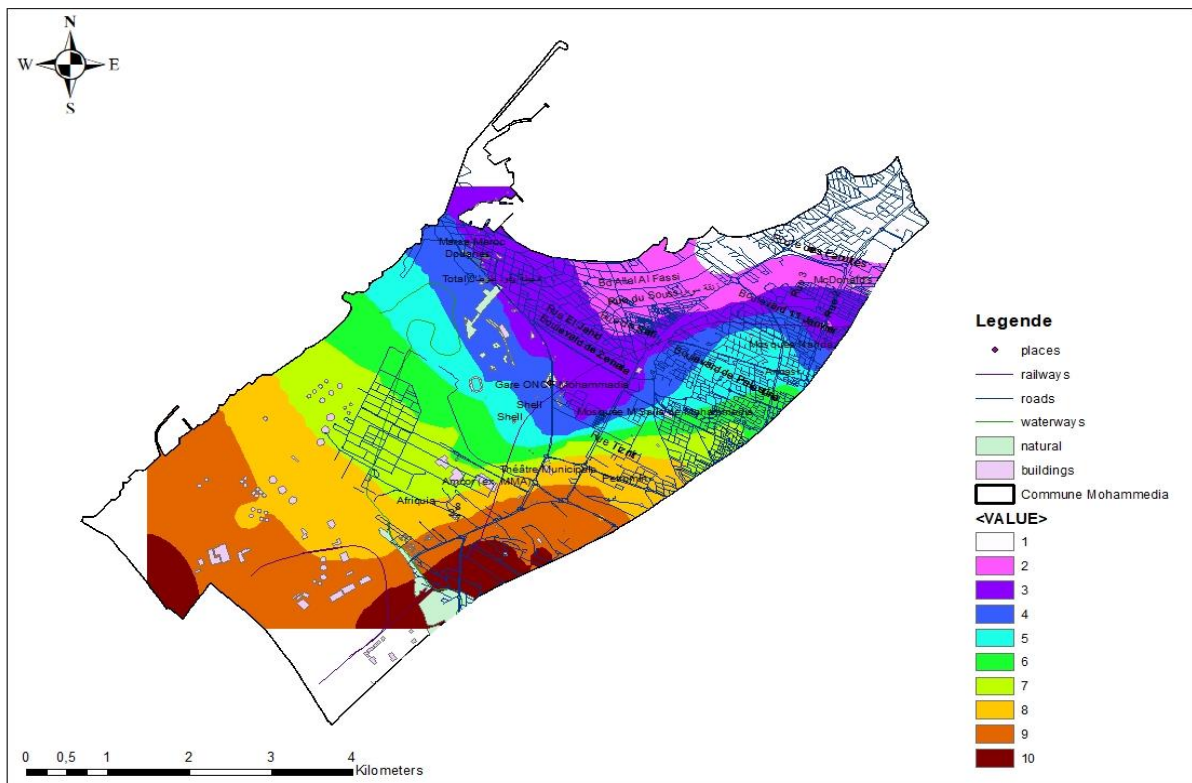
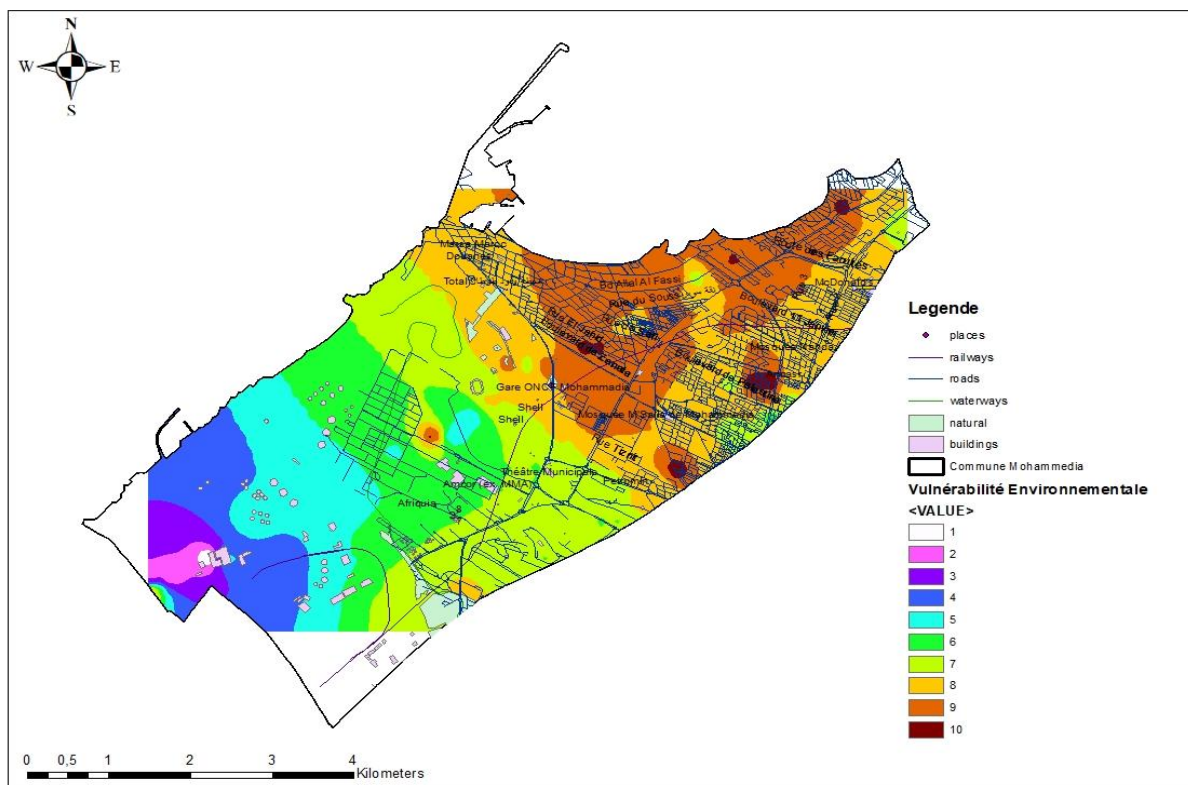


Figure 8: Mohammedia's environmental vulnerability map



3. Discussion of the results and analysis of the risk of flooding in Mohammedia

3.1. Interpretations of vulnerability outcomes

Before sharing with the hazard perimeters, the first objective of this study is to map vulnerability at the level of Mohammedia. The figures represents spatially, qualitatively and quantitatively the different human, environmental and material vulnerabilities. The highest vulnerability rates are concentrated in the fuel industrial area (Samir) where the Mohammedia refinery is located, as well as the upper part of Mohammedia Al Aliya and the industrial area. The sectors of medium vulnerability are found in the lower Yacoub El Mansour area and there is a low vulnerability in the seaside area.

There is a high concentration of human vulnerability in the lower Mohammedia area, the port thus the Siesta, Mannesmann, La Colline, Houria and Al Louizya, while the Mohammedia industrial area represents a low human vulnerability.

Concerning the material stakes is concentrated in the industrial fuel zone and the industrial zone of Mohammedia also they are concentrated at the level of Oued Maleh.

The map of material vulnerability is the opposite of that of the environment. Indeed, sectors with low material stakes have important vulnerable environmental targets. Thus, this environmental vulnerability is mainly located in the East part of Mohammedia due to the presence of the main and secondary road network, not to mention the stormwater discharge collectors.

We can conclude that at the Mohammedia level, there is a dominance of human vulnerability which translates into risk to the population. Thus, there are other risks concerning the road network infrastructure and stormwater discharge collectors, in addition to the risk of Oued Maleh. Not to mention the risk of industrial areas that are located in flood risk areas.

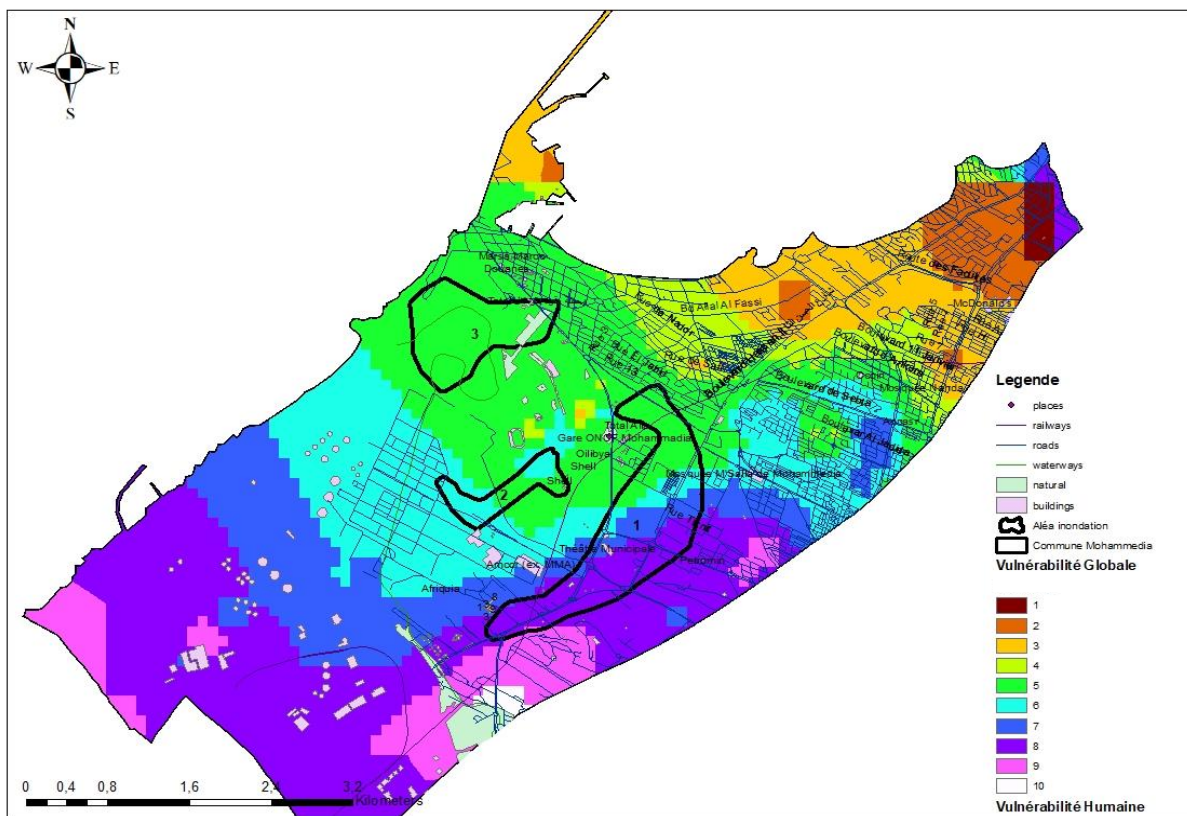
3.2 Interactions between hazard and vulnerability

After defining the different vulnerabilities, the last step of this study is to merge them with the hazard zoning. Direct risk visualization using the superposition of hazard and vulnerability layers therefore allows decision-makers to gain a better understanding of the terrain to better manage the risk of flooding in these areas.

The global vulnerability map has made it possible to classify vulnerable areas in relation to the flood and which may have more damage.

There are 3 flood risk areas in Mohammedia, which are classified according to their vulnerability to damage.

Figure9: Flood risk at Mohammedia



Based on these results, these areas can be categorized according to the level of risk:

Zone 3: The low Mohammedia area which represents a level of 5 depending on the vulnerability scale.

Zone 2: This area represents a vulnerability level between 5-6.

Zone 1: The high mohammedia area which represents a vulnerability between 5-8.

The following table represents areas at risk based on the level of vulnerability:

Tableau2: Areas at risk on the scale of vulnerability in Mohammedia

Areas at Risk	Vulnerability level
Area 1	5-8
Area 2	5-6
Area 3	5

This analysis showed the strong preponderance of human vulnerability in global vulnerability and the need for managers to take into account vulnerability very precisely and locally, due to very high spatial variability.

This method, which can be extrapolated to any area, provides global vulnerability maps but also specific vulnerable targets, and has the advantage of being able to superimpose them on the various hazard maps that already exist for a direct reading of specific risks. As a result, the risk vision becomes more relevant, with the possibility of new interactions between types of vulnerability and types of hazards.

This study will help managers in their decisions, initiatives and structural response to floods and give priority to relief in the most vulnerable areas.

Finally, although the tool has limitations that must be known when using it, its innovative nature, its scalability and flexibility of adaptation make it a very useful tool for managers who can, if necessary, complete or update the hierarchical tree structure with new targets, or refine the vulnerability functions by making the panel of experts more adapted to their wishes.

4. Conclusion

This analysis made it possible to define priorities with regard to flood vulnerability by giving a classification of areas according to the vulnerability index. This ranking provides the basis for the action plan to define the quantification of damage.

According to the interpretations of the vulnerability results, the dominance of the human vulnerability index at Mohammedi level, as well as the vulnerability of industrial areas and infrastructure, has been observed.

This work provides managers and stakeholders with an effective tool for urban flood management and to find effective flood protection measures to limit the risk of flooding and ensure adequate rainwater drainage.

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